SOIL MANAGEMENT

THE WILEY AGRICULTURAL SERIES

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SOIL MANAGEMENT

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PREFACE

THE purpose of this book is primarily that of acquainting the student with the applications of those scientific facts and principles which are of use in planning constructive systems of soil management and in increasing the productive capacities of soils. It is assumed that the student has had courses in chemistry, botany, geology and physics and that he is familiar with the ordinary vocabularies of these sciences.

Many of the applications of the above sciences which are of interest to the more advanced student of soils are not touched upon in the following pages except perhaps in a very brief way. This is for the reason that the book is intended for use in a required course in soils in an agricultural college many of the students in which are not primarily interested in the more intricate phases of the subject and have little or no need for the course except as it may be useful to them in practice or in understanding practice on the farm.

It has not been deemed desirable to attempt to present any large part of the data on which the author's conclusions are based. For this reason illustrative data have been chosen from whatever sources the most conclusive evidence could be secured. In the absence of any reason for doing otherwise, these data have been selected from those published by the Ohio Agricultural Experiment Station and College. Where the book is used in other states it is hoped that illustrative data from those states can be substituted.

It is assumed that the classroom discussion of the subject

will be supplemented by laboratory studies designed to fix more definitely in the student's mind some of the more important facts and principles which lend themselves to laboratory demonstration. Thus a supplemental guide has been prepared for use in the required course in soils at the Ohio State University which has been found to stimulate additional interest on the part of the student and to make the classroom instruction more effective.

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SOIL MANAGEMENT

CHAPTER I

FACTORS AFFECTING THE GROWTH OF CROPS

CROP growth is influenced by many factors. These may be conveniently classified into three groups, viz.: climatic biotic and soil. Among the climatic factors are rainfall, light, temperature and atmosphere. Under the biotic group may be included man, animals, other plants and the crop itself in relation to its environment. The soil factors include all those physical, chemical and biological properties of and processes in the soil which affect its capacity to supply the crop with the necessary nitrogen, mineral elements and water.

These various factors may be either positive or negative, depending upon the conditions. They are all very definitely interrelated. It is seldom, if ever, possible to have all of them operating at the optimum. The success of the farmer in growing crops is determined by the extent to which he is able to keep the several factors under control; to modify their influence to suit the needs of his crops; and to choose the crop to fit the conditions which obtain.

CLIMATIC FACTORS AND CROP GROWTH

The climatic factors are so related to each other in their effects on crop growth as to make their separate consideration difficult. The amount of water available to the plant

is not so much dependent upon the rainfall as upon the rainfall-evaporation ratio; the atmosphere is in competition with the plant for water, particularly in semi-arid regions. The photosynthetic processes in plants are dependent upon light, but the intensity of the sunshine is ordinarily much in excess of the requirements of plants; length of day is the important phase of the light factor. Certain crops grow best in cool climates, but this may at times be related to the larger supply of available moisture under such conditions rather than to the direct effect of temperature.

Baker and Finch have shown the geographic locations of the more important crops and have indicated the climatic conditions associated with these locations. It is not feasible to discuss the relationships between climatic factors and crop distribution in detail, but some of the more important cases will be considered. It seems desirable to point out that the farther removed a farm is from the center of production of any crop the more difficult it is for the farmer to grow that crop satisfactorily, until a point may finally be reached at which it is no longer advisable to make the attempt.

CLIMATIC FACTORS AND CROP DISTRIBUTION

The wheat crop does not thrive in warm, humid climates because of the competition of wheat diseases under such weather conditions. The growing season for wheat must be at least 90 days. The average annual precipitation of wheat regions of highest acre production is between 30 and 35 inches. The seasonal distribution of the rainfall is important. The most favorable conditions are found where a cool, moderately moist season, during which the tillering process continues freely, develops gradually into a warm, bright and somewhat dry harvest period, which favors the development of a hard wheat and is unfavorable to the growth of fungus diseases.

The corn crop finds its geographic range limited by tem-

perature and rainfall. In the Corn Belt of the United States the mean summer temperature is between 70° and 80° F. with a night temperature averaging approximately 60°. The season between frosts is about 140 days. The rainfall amounts to between 25 and 50 inches with at least 7 inches during July and August.

It is apparent that a good wheat climate is not the same as that described for corn. Nevertheless the two crops are grown successfully in rotation in temperate zones by reason of the fact that wheat is essentially a winter and spring crop while corn is a summer crop. The two crop seasons overlap somewhat and for that reason the best wheat sections are often only moderately satisfactory for corn. Spring wheat is substituted for winter wheat in the cooler portions of the world, but cannot be grown in the Corn Belt to advantage because it matures too late in the summer season.

This same principle is involved with the oats crop, which also is adapted to cool, moist climates and is even more seriously affected than wheat by high temperatures. Oats can be grown successfully in warm climates only when it can be sown in the fall and have its growing season largely during the winter and spring months. Potatoes also grow best in moist, cool climates, somewhat north of the Corn Belt in the United States, under conditions where the tubers can be produced while the temperature is reasonably low. In Algeria they are planted in November and December and harvested from January to May.

Rice is an interesting crop by reason of its high water requirements, being grown to best advantage under conditions in which irrigation can be practiced. In Louisiana the water requirement of rice is found to amount to approximately ½ inch per day as an average for the 90-day growing period. The rainfall during this period amounting on the average to 20 inches, the remaining 25 inches must be supplied by irrigation. The temperature requirements are at least 75° as a mean for the growing season.

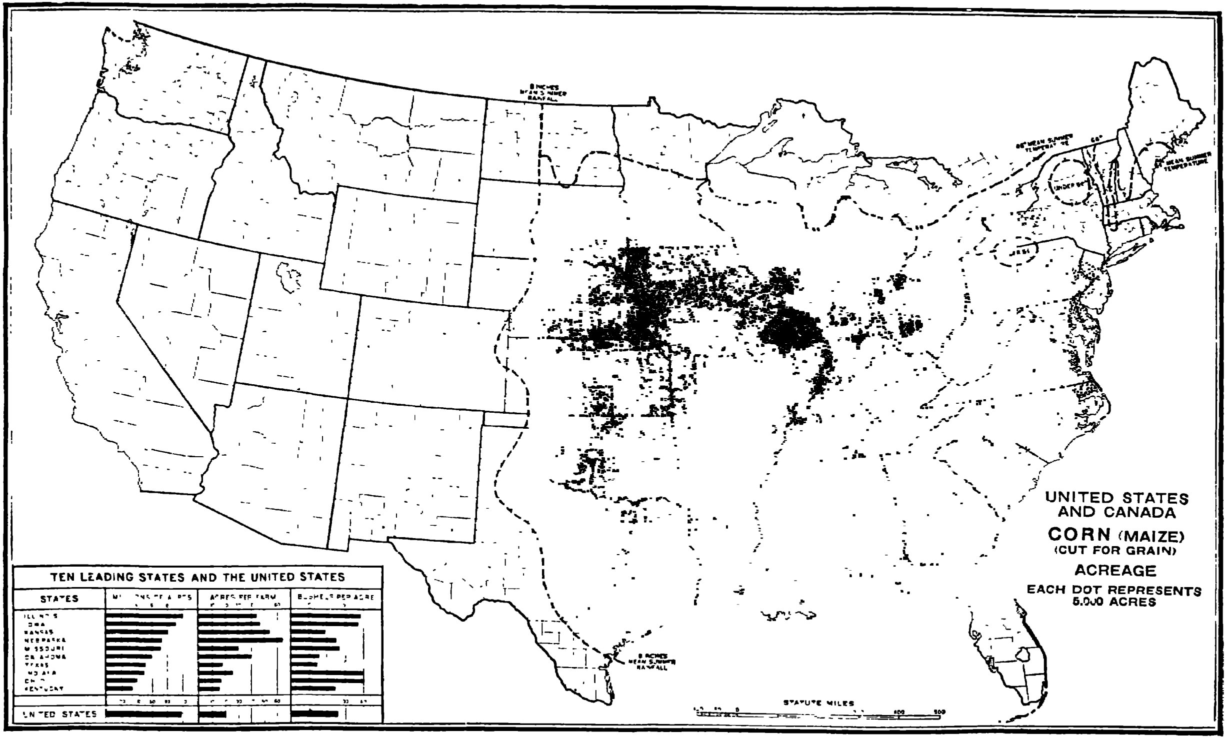

Fig. 1.—"The farther removed a farm is from the center of production of any crop the more difficult it is for the farmer to grow that crop satisfactorily until a point is reached at which it is no longer advisable to make the attempt." Map from Finch and Baker's "Geography of the World's Agriculture."

Cotton is another warm climate crop. The northern limit of cotton growing is approximately a mean summer temperature of 77° and a frostless season of 200 days. The annual precipitation requirements are found to be in excess of 23 inches. Within these boundaries the Cotton Belt is found with the best cotton being produced when the weather is warm and moderately moist from April to August and is dry and cool in the autumnal picking period.

The sugar beet has its highest content of sugar in northern latitudes. As to whether this is entirely related to temperature seems doubtful, the length of day during the growing season apparently having considerable to do with the percentage of sugar. On the other hand, sugar cane grows best under conditions in which the temperature is uniformly high, the sunlight strong and the showers frequent. Cool and cloudy weather reduces the yield of cane and increases the percentage of fiber with a consequent reduction in sugar content.

The oats and barley crops are important northern crops by reason of their short season requirements. In Finland and Sweden these crops are grown nearly to the Arctic Circle. Barley can be grown in high altitudes where the summers are soon over and in semi-arid sections where the wet seasons are short.

Two excellent examples of drought-resisting crops are found in olives and in the sorghums. The olive is sensitive to frost, but grows well in arid climates. Its surface root development enables it to absorb moisture after a light rain and its leaves are of such a character as to retard evaporation. Kafir, milo and other sorghums are grown in Texas, Oklahoma and Kansas with an average annual rainfall of from 15 to 30 inches. During a period of drought these crops cease growth, but go ahead normally as soon as rain occurs.

BIOTIC FACTORS AND CROP GROWTH

Mention has been made of the fact that the wheat crop suffers, in warm, humid climates, from parasitic fungi which find a favorable environment under such conditions. The growth and distribution of crops is influenced to a considerable extent by the degree to which the insects, fungi, bacteria and other parasites find conditions favorable for their development. Many of these biotic factors are negative and operate in opposition to the growth of plants. Notable exceptions to this may be cited in the organisms which live in the soil and have to do with making the organic, the atmospheric and the mineral elements available. It seems desirable in this discussion to include these, as well as all of those parasitic organisms which harbor in the soil, among the soil factors, since the only opportunity for their control lies in some operation which also alters the physical or chemical properties of the soil.

The effect of crops on those grown in association with them as well as on the following crops merits considerable attention. The explanation of the injury to the crop due to weeds is probably not so simple as might be anticipated from the ordinary statement of the fact of their competition with the crop for water, soil elements and light. Similarly the differences in the yield of corn following clover and timothy are not related entirely to the known differences in the effect of these crops on the total content of nitrogen in the soil. These and other points related to crop succession will be considered in somewhat greater detail in the chapter on "Crop Rotation."

Man is the most important biotic factor since, in addition to his capacity to regulate in part the properties of and processes in the soil and to influence indirectly the climatic factors, he is also able to control to a certain extent the other biotic factors which influence the growth of crops. It must also be recognized that by breeding and selection it is

possible to develop new varieties and strains which may tolerate a wider range of climatic conditions; may have a greater resistance to disease; or may have a greater capacity to secure from a given soil the elements required for larger crop yields. These may operate in opposition to negative factors or in such a way as to take better advantage of positive factors influencing the growth of crops.

SOIL FACTORS AND CROP GROWTH

The soil factors are variables depending upon the climatic and biotic factors in operation. Productivity is not a property which is inherent in the soil itself but must be considered in relation to the environment of the soil and the requirements of the crops grown. The effect of the factors other than the soil as they operate to influence the growth of crops from year to year may be observed in a study of the fluctuations in yields of plots in the long-continued fertilizer tests at the several experiment station farms. Examples of these may be noted in the following table, which records the yearly yields of crops on plots 8 and 11 of the five-year rotation fertilizer series at Wooster, Ohio. Plot 8 received a phosphate-potash fertilizer while plot 11 received a complete fertilizer. Both plots were limed whenever the need seemed apparent.

The soil treatments for each crop were uniform throughout the period of the test except as changes in the frequency and type ot mechanical operations may have been necessitated by the weather. The climatic and biotic factors were not controlled, although their influence was undoubtedly somewhat modified by the soil treatments. The differences in yields noted from year to year are such as to make it apparent that the productivity of a soil must be considered in relation to the environment in which the soil happens to be.

On the other hand, it is possible to effect very remarkable changes in the productive capacity of any soil subject to the influence of any given climatic and biotic factors. Thus in the

TABLE I

FLUCTUATION IN YIELDS DUE TO UNCONTROLLED FACTORS

Plots 8 and 11, Ohio Experiment Station, Wooster

	Yield per Acre									
	Corn, Bu		Oats, Bu		Wheat, Bu.		Clover, Cwt		Timothy, Cwt	
Plots	8	11	8	11	8	11	8	11	8	11
Year										
1906	69	73	46	53	35	45	28	36	41	41
1907	57	64	27	30	24	29	32	42	52	59
1908	46	49	56	53	34	41	50	46	42	53
1909	38	53	52	54	31	32	28	31	.	.
1910	16	18	53	48	20	27	36	40	43	45
1911	72	73	33	37	14	24	21	23	30	29
1912	.	.	58	61	10	11	39	41	35	36
1913	38	42	20	21	27	38	13	12	38	44
1914	47	54	41	59	37	35	15	18	36	29
1915	56	17	55	65	28	32	20	23	..	
1916	41	41	43	46	31	37	26	34	33	35
1917	62	65	71	71	31	36	27	35	43	38
1918	38	46	78	81	24	33	23	22	31	41
1919	60	68	33	38	25	27	23	29	38	33
1920	57	56	63	63	15	25	40	41	52	45

same fertilizer series at Wooster as that mentioned above, the average annual acre yield has varied between wide limits depending upon the fertilizer treatment the soil has received, all of the other factors being constant except as they may have been modified indirectly by the fertilizers applied.

Increases of from 8 to 35 bushels of corn and corresponding increases in the yields of other crops, for which the soil treatments are responsible, indicate something as to the possibilities of influencing the productive capacities of soils through the control of soil factors alone. It is essential to keep in mind, however, that the increased yields produced as a result of the application of fertilizers, manure and lime-

TABLE II

IMPROVEMENT IN YIELDS DUE TO SOIL TREATMENTS

Average Acre Yields Ohio Experiment Station, Wooster. Five-Year Rotation, 1900 to 1918

Variation in Treatment	Corn, Bu.	Oats, Bu.	Wheat, Bu.	Clover, Cwt.	Timothy, Cwt.
No fertilizer	26	30	12	12	22
Acid phosphate	34	43	21	14	27
Phosphate and potash	43	45	22	22	28
Complete fertilizer	48	52	31	25	31
Fertilizer and limestone	54	53	32	33	41
Manure	55	47	29	34	42
Manure and limestone	61	48	33	43	55

stone may have their explanation in part in their capacity to modify the influence of the climatic and biotic factors. It must also be remembered that for any given plant the climatic factors limit its distribution and that beyond a certain distance from the climatic crop center the plant may not thrive no matter how carefully the soil is managed. The farmer also has the alternatives of modifying the soil to fit the needs of a given crop or of choosing another crop which may be more nearly adapted to the soil under the environment in which it happens to be.

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CHAPTER II

NITROGEN AND MINERAL REQUIREMENTS OF CROPS

In order to reach some conclusion with reference to the nitrogen and mineral requirements of plants it seems desirable to examine rather carefully into their composition as shown in the analytical laboratory. It is now recognized that such analyses do not necessarily give an exact index of the quantitative need for the several elements, but they do provide a clue to plant requirements and permit of fairly exact estimates of the amounts of the mineral nutrients removed from the soil.

THE COMPOSITION OF PLANTS

A large amount of analytical data is available on the composition of plants, much of which is of doubtful accuracy because of the necessity of the use by early analysts of methods which are now known to have been faulty. Forbes has presented analyses of some of the common American crops made by the use of modern methods which should be correct, subject of course to the limitation that they represent only a relatively small number of samples. From these analyses, supplemented where necessary by those of other modern investigators, the following table showing the composition of the corn, wheat and clover plants has been compiled. The quantities of carbon, hydrogen and oxygen were calculated on the basis of the ratios in which they are found in starch after having subtracted from the weights chosen the quantities of nitrogen and of ash ele-

ments which analyses had shown the plants to contain. These calculations are based admittedly on an incorrect assumption, since plants contain water, fats, proteins and other organic substances, with varying ratios of carbon, hydrogen and oxygen. The figures are of value, however, in showing the relatively large amounts of these elements in plants.

TABLE III

CHEMICAL COMPOSITION OF CORN, WHEAT AND CLOVER

Pounds per Ton of Produce

Elements	Corn		Wheat		Clover
	Grain	Stover	Grain	Straw	Hay
Oxygen	961.5	943.6	957.6	918.9	928.7
Carbon	866.9	848.1	860.6	852.9	831.7
Hydrogen	121.0	118.4	120.1	119.1	116.5
Nitrogen	27.8	17.5	33.0	5.6	41.6
Potassium	6.8	31.3	10.4	15.9	31.0
Phosphorus	5.2	1.9	7.1	0.7	3.3
Calcium	0.2	9.1	1.0	4.1	22.8
Sulphur	2.9	3.4	3.9	3.0	3.5
Magnesium	2.1	1.7	2.6	1.2	5.4
Sodium	0.5	1.2	0.6	4.1	1.2
Chlorine	1.2	5.7	1.6	3.9	4.7
Silicon	0.1	13.7	0.5	39.7	2.3
Iron	0.1	0.6	0.2	0.2	0.6

VARIATION IN MINERAL CONTENT OF WHEAT

In order to determine the variation in composition of plants Forbes analyzed samples of wheat selected from 13 different plots of the fertilizer series on the Wooster, Ohio, experimental farm. Calculated on the basis of the dry weights of grain the content of the several elements found in the ash varied as indicated in Table IV.

TABLE IV

RANGE IN MINERAL COMPOSITION OF WHEAT GRAIN (FORBES)

From 13 Plots Variously Fertilized, Wooster, Ohio

Pounds per Ton of Dried Material

Element	Minimum	Maximum	Per Cent Variation
Potassium	8 84	10.46	18.3
Phosphorus	6 74	8.12	20.5
Calcium	0 86	1.14	32 5
Sulphur	4 26	5 16	21.1
Magnesium	2 78	3 08	10.8
Sodium	2 26	3 36	48.7
Chlorine	1 46	2.24	53.4

FACTORS AFFECTING THE COMPOSITION OF PLANTS

Within certain limits the content of any one of the mineral elements in the plant is proportional to the quantity of that element available to the plant in soluble form. Pember found, for example, that when barley plants were grown in culture solutions containing varying amounts of phosphates, they absorbed, from the solutions which were more concentrated with respect to phosphorus, approximately three times the quantity of that element as seemed to be required for optimum growth. To a certain extent, therefore, it is possible to determine the amount of available mineral nutrients in the soil from an analysis of the plant, and such a method of soil analysis has been suggested. It is also probable that certain of the mineral elements are present in plants not because they are required, but because they are dissolved in the soil water and the plant has no means of preventing their entrance.

As would be expected, plants differ in their composition depending upon the species and variety to which they belong, their stage of growth at the time of analysis and the part of the plant analyzed. Legume hays are notable for

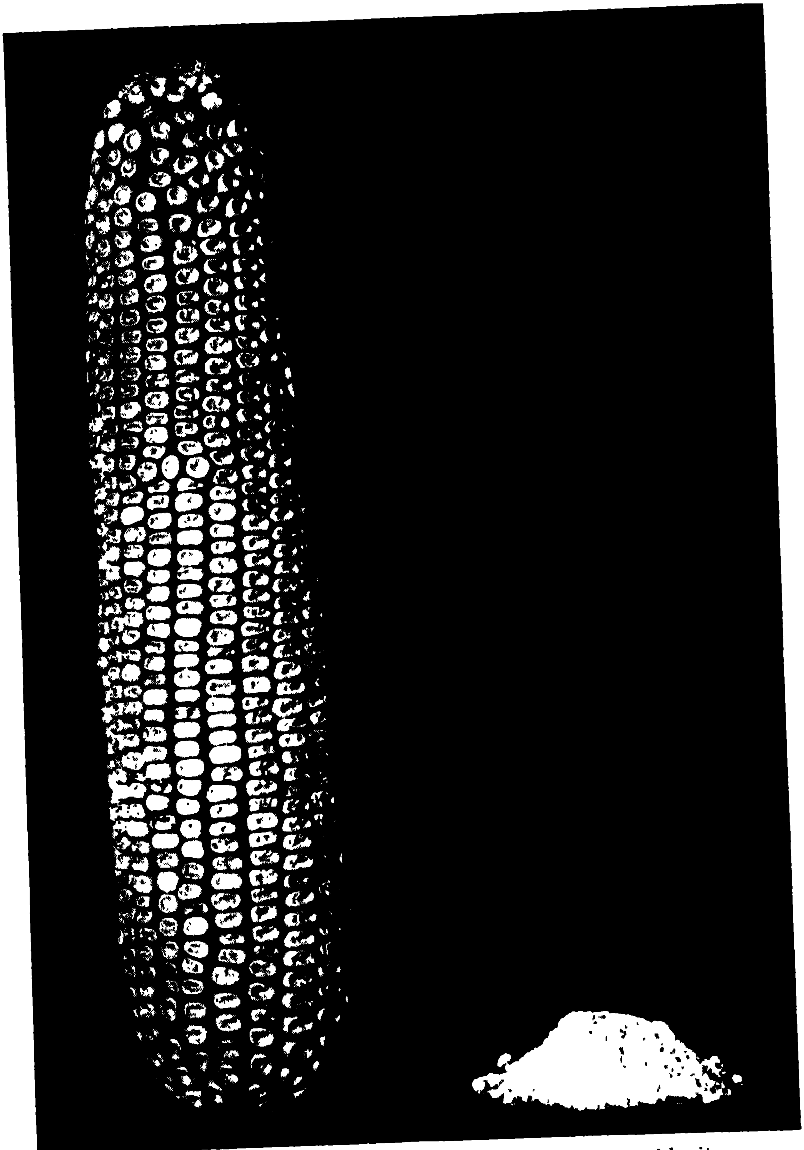

FIG. 2.—An ear of corn and the ash from burning one like it.

their high content of nitrogen. They also contain considerably larger amounts of the ash elements than do the stalks of most other crop plants. Cereal straws are high in their content of silicon. Tobacco contains relatively large percentages of potassium and calcium. Considered from the point of view of the quantity contained in an acre of produce, the crucifers are high in sulphur. Rape is an example of a non-legume having a nitrogen content equal to that of clover. The protein content of soybean seed has been reported to vary from 30 to 45 per cent, depending upon the variety. Corresponding differences have been noted in the composition of the seed and other parts of the several varieties of other crops.

Ordinarily, the percentages of nitrogen and mineral elements in plants are greatest during the earlier stages of growth, while starch accumulates more rapidly as the crops mature. With the production of seed there is a movement of nitrogen, phosphorus and magnesium to this part of the plant with a tendency to concentrate in the seed coats. Potassium and calcium tend to remain well distributed through the plant, the major portion being found in the stalks at the time of maturity. The relative rate of removal of the nitrogen and essential mineral elements from the farm in crops is determined, therefore, by what part of the crop is sold.

ESSENTIAL AND NON-ESSENTIAL ELEMENTS

Arsenic, iodine, zinc and other elements of widely different properties are found in plants when grown on soils containing them. The extent to which these elements function in the plant is uncertain. A few of them have been shown to accelerate growth in dilute concentrations and to be toxic when supplied in larger amounts. Some uncertainty also exists as to the function, if any, of sodium, chlorine and silicon. Plants have been grown to maturity in the absence of these elements except in such quantities as

unavoidably contaminate most culture solutions. Yet it has been shown that sodium can be substituted in part for potassium. However, the elements which are of most significance by reason of their known specific functions are carbon, hydrogen and oxygen, which are derived largely from water and carbon dioxide, and nitrogen, potassium, phosphorus, calcium, sulphur, magnesium and iron, which are taken up in solution from the soil.

THE MINERAL THEORY

Under conditions in which the soil has been farmed for some years and the virgin productivity has been considerably reduced, it would be expected that the yield of crops would be determined in large part by the quantity of that soil element which was present in smallest amount in available form, as compared to the need of the plant for it. This was the assumption on which Liebig based his " Mineral Theory." This theory stated that " the crops on a field diminish or increase in exact proportion to the diminution or increase of the mineral substance conveyed to it in manure." If the statement of the theory were made to include all the factors related to the growth of crops, such as water, nitrogen, carbon dioxide, light, heat, soil reaction and others, it would be more nearly correct.

Another phase of the problem which Liebig's theory does not take into consideration is that any factor in excess may become a limiting factor. Further, even if all factors were supplied at the optimum the limit of growth of the plant is finally fixed by the capacity of the protoplasm to do work. Taking these points into consideration, if all factors were at the optimum except one, the yield of the crop would be expected to be proportional to the quantity of that factor supplied up to the optimum. However, all of these factors are interrelated and the effect of a deficiency of any one is determined by the nature of its relationships to the others as well as by its own specific need by the crop.

EFFECT OF VARIOUS FERTILIZER SALTS ON CROP YIELDS

Of interest in this connection are the data available from experiment stations showing the effect of fertilizer salts, when applied singly and in combination, on the yields of crops. An example of this may be selected from the fertilizer series on the Ohio Experiment Station farm at Wooster:

TABLE V

EFFECT OF FERTILIZER SALTS ON CROP YIELDS (WOOSTER)

19-Year Average Acre Increases—5-Year Rotation

Crop	Check Yield	Acid Phosphate	Nitrate of Soda	Muriate of Potash	Lime and Limestone	All Combined
Corn, bu.	25 6	8 6	6 0	5 9	5 6	23 3
Oats, bu . . .	30 0	11 6	5 0	3 4	5 1	18 1
Wheat, bu.	12 2	8 0	2 2	0 6	3 5	16 2
Clover, cwt.	11 6	4 0	3 5	1 0	6 1	15 8
Timothy, cwt .	22 0	3 0	4 9	0.5	8 4	11 6

The data show that each fertilizer salt has increased the If the conception of one limiting factor operating at a time were strictly applicable, one would not expect nitrate of soda to increase the yield when acid phosphate, as indicated by the effect of its use, was the limiting factor. Nitrate of soda may increase the solubility of soil phosphorus. More probably the explanation of its effectiveness, even in the absence of acid phosphate, lies in some more complex relationship which exists between the various mineral factors which such a simple law does not explain. The stimulation of microbiological activities and the consequent production of greater amounts of available nitrogen and mineral nutrients merit consideration in this connection.

THE SOIL-PLANT-SOIL CYCLE

It has been found that crop yields can usually be increased, even in humid climates, by the addition of irrigation water. It has also been shown that plants are able to utilize carbon dioxide at a more rapid rate than it is supplied from the ordinary atmosphere. In humid climates, however, there is a normal water and carbon dioxide cycle which is completed in a relatively short time. With those elements which are secured by plants from the soil the cycle of their return to the soil is much slower and in large part never completed, particularly in areas devoted to cultivated crops. The problem in this case becomes one of determining the rate at which these elements can continue to be supplied to successive crops from the soil. Where soil has been under cultivation for some years it is not uncommon, in fact it is the rule, that additions of soluble nitrogen, phosphorus and potassium and also the use of basic compounds of lime and magnesium will increase the yield. In some cases sulphur and in others salts of iron have been applied to good effect.

THE PROBLEM OF SOIL MANAGEMENT

In the management of his soil the intelligent farmer not only attempts to regulate the rate at which the essential mineral elements and nitrogen are yielded up to the crop, but also endeavors to regulate such factors as water, temperature and soil reaction and to control certain negative factors such as diseases and insects. To a limited extent it is also possible for him to control the supply of light and carbon dioxide. The problem is, therefore, much larger than that of simply analyzing the plant and returning the elements to the soil in quantities corresponding to their rate of removal.

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CHAPTER III

WATER REQUIREMENTS OF CROPS

From 97 to 98 per cent of the corn crop when harvested and air dried at maturity is made up of oxygen, carbon and hydrogen in combined forms. Similar percentages of the other cereal crops and of the grasses are constituted by these three elements. The carbon is derived almost entirely from carbon dioxide which finds its entrance into the plant by way of the stomatal openings in the leaves. The hydrogen and oxygen are secured largely from water which is taken up through the root systems of plants. As a result of photosynthetic processes in the leaves, simple organic compounds are produced from these two substances which alone, or together with nitrogen and the mineral elements, are later synthesized into the several more or less complex organic compounds found in plants.

WATER AS A LIMITING FACTOR

The supply of carbon dioxide available for plants is not to any large extent under the control of the farmer. Experimental tests indicate that by increasing the concentration of the carbon dioxide in the atmosphere surrounding the plant, both the rate of growth and the total amount of produce can be increased. The application of this to practice is limited almost entirely to greenhouse cropping. Water is of considerably greater importance than carbon dioxide in practice since the opportunities for controlling the supply are abundant. Furthermore, a deficiency of available water is probably more often a limiting factor in crop growth than any other one thing. Johnson, writing in 1870, said: " It

is a well-recognized fact that next to temperature the water supply is the most influential factor in the production of the crop." After studying the relation between rainfall and corn yields in the Middle West, Smith later showed that "In a latitude and elevation favorable for the production of crops precipitation has first place and temperature second."

RATE OF TRANSPIRATION OF WATER BY PLANTS

Numerous studies have been made of the amount of water transpired by plants during their growing periods.

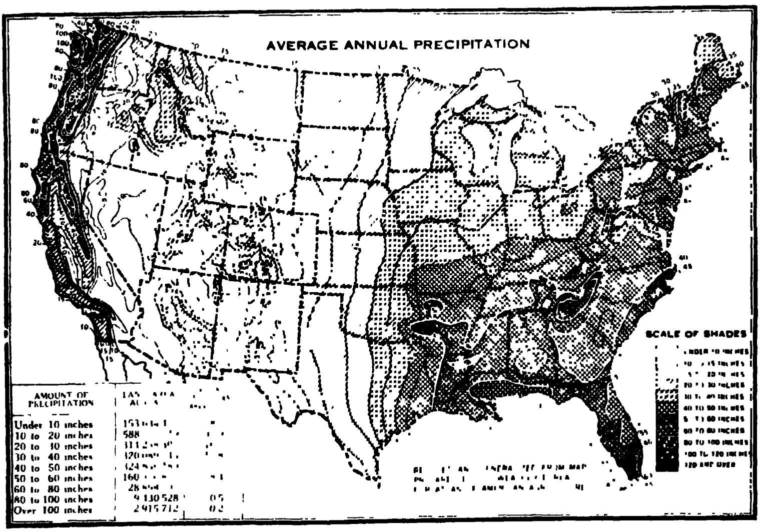

FIG. 3.—"In a latitude and elevation favorable for the production of crops precipitation has first place and temperature second" Map from Yearbook of U. S. D A. for 1921.

Among the more recent of these investigations may be mentioned those of Kisselbach, in Nebraska, who studied in considerable detail the water requirements of the corn plant. He found that the rate of transpiration of water increased from week to week until the plant had developed its maximum leaf area. During the five weeks following this stage

of growth fully half of the total transpiration occurred. The actual amount of water given off varied from 230 to 296 pounds for each pound of dry matter produced. Kisselbach's data would indicate that a 100-bushel corn crop would require approximately 1300 tons of water, an amount sufficient to cover an acre to a depth of 11 inches. It is interesting to note that this is practically identical with the average total rainfall in the Corn Belt for the three months, June, July and August.

CORRELATION BETWEEN RAINFALL AND YIELD OF CORN

Smith found that the July rainfall was more important in the Corn Belt than that of any other month. Concerning the corn yields in Ohio he writes that " between 2 and 6 inches the yield increases at an average rate of 2.5 bushels per acre for each increase of 1 inch of July rainfall." If in addition the rainfall of June and August was considered, the acre production and precipitation curves for the 60-year period, 1854–1913, were found to be very nearly parallel. This correlation between rainfall and corn yield was found to obtain throughout the Corn Belt.

The relationship between rainfall and corn yield is also very nicely shown in the records available at the Wooster, Ohio, experimental farm. The corn, of which the acre yields are given below, was grown in rotation with oats, wheat, clover and timothy. The soil was limed and received a phosphate-potash fertilizer. The opportunity for a lack of water to become the limiting factor was therefore considerably better than it would be under average conditions.

The highest average yields were produced at an average rainfall of 11.61 inches. The distribution of this rainfall within the three-month period was of considerable importance. Thus the highest yield produced in the 19 years was 73.93 bushels per acre in a year in which the rainfall was 4.82, 3.32 and 3.58 inches for June, July and August respectively, while only 47.43 bushels of grain were produced when

TABLE VI

RELATION BETWEEN RAINFALL AND CORN YIELDS, WOOSTER, OHIO

June, July and August Rainfall—Limed and Fertilized Plots

Number Years Included in Group	Average Total Rainfall, Inches	Average Acre Yield	
		Grain, Bu	Stover, Cwt.
3	6 96	26 67	18 53
4	9 39	46 82	20 00
4	11 61	62 63	28 45
4	14 96	55 81	24 30
4	17 83	57 48	24 95

the rainfall was 6.33, 1.23 and 5.00 inches, respectively, for the same three months another year.

THE CRITICAL POINT IN WATER SUPPLY IN IRRIGATION STUDIES

Some idea of the relationship between water supply and crop yield may also be secured by a consideration of irrigation investigations of Western United States. The point of greatest economic importance in these studies is that of determining when to discontinue increasing the application of water to any one acre and to begin enlarging the acreage under cultivation. Incidentally these studies show the critical point with additional increments of water. The following data chosen from the work of Harris and Pittman in Utah are typical. The soil in this case was well manured so that a lack of mineral nutrients and nitrogen did not operate to limit the growth of the crop.

The optimum quantity of irrigation water, as nearly as the test indicates, was 20 inches which, together with the 2.65 inches rainfall, makes a total of 22.65 inches. Experiments with other crops showed similar production curves, the critical point varying with the crop. The explanation of the critical point will be considered later.

TABLE VII

YIELD OF CORN WITH VARYING AMOUNTS OF IRRIGATION WATER

Six-Year Average Acre Yields—Utah

Irrigation Water, Acre Inches	Grain, Bu.	Stover, Cwt
0*	75.9	78.4
5	91.4	89.7
10	92.5	85.0
20	99.1	97.1
30	95.7	95.4
40	90.0	90.0

* June, July and August rainfall average total 2.65 inches. Average total yearly rainfall 17.12 inches.

CROP DISTRIBUTION AS RELATED TO RAINFALL

Considerable attention has been given to the water requirements of the corn crop by reason of the very general importance and distribution of this crop in the United States. The water requirements of other crops differ somewhat from those of corn, but within the area best suited to any crop water is likely to be a highly important limiting factor. As compared with temperature and other climatic factors the importance of rainfall can be seen in the fact that deserts and populous agricultural sections often extend at nearly right angles to the climatic zones. Passing westward in the United States from the humid to the arid sections there is a gradual change in the predominant type of natural vegetation and of cultivated crop. Thus as the available water supply becomes more limited, kaffir corn and milo maize take the place of corn. Under conditions in which the wet seasons are too short for wheat, barley may be substituted. Finally the xerophytic plants such as cactus and sagebrush entirely take the place of the ordinary crop plants and the desert begins.

AN ECOLOGICAL CLASSIFICATION BASED ON WATER RELATIONSHIPS

Most of the crop plants and the more valuable forests belong to the ecological group known as the mesophytes, which occupy in their water relationships an intermediate position between the xerophytes and the hydrophytes. Typical members of the last-named group are found in such plants as water lilies. Of the hydrophytic plants of agricultural importance may be mentioned swamp rice and cranberries. These crops are grown with greatest success under conditions of water supply which would be fatal to the staple farm crops. Xerophytic plants are also found distributed through the humid regions on rock surfaces or in locations where the water holding capacity of the soil is very small. A good review of the water relationships of plants is given by Duggar.

THE RAINFALL-EVAPORATION RATIO

The air is in competition with the plant for that water which the soil retains in opposition to the pull of gravity. The rainfall-evaporation ratio is therefore more important than the total rainfall. This ratio is found to vary from more than one in the typical forest centers of the Atlantic seaboard, the Gulf Coast and the Great Lakes region and from 0.6 to 0.8 in the natural prairie sections of Iowa and Illinois, on down to the desert which may be said to begin when the ratio falls to less than 0.2. The quantity of water required for irrigation purposes in the arid regions is, therefore, not a reliable guide to the amount of rainfall required for optimum growth of the same crop in humid climates. In the absence of opportunity to supply water by irrigation, the distribution of crops as between semi-arid and humid climates will be determined quite largely by the water requirements of the crops and the rainfall-evaporation ratio.

SOIL MANAGEMENT AS RELATED TO WATER CONTROL

The farmer is able to exercise some influence over the rate of evaporation of water from the soil. He cannot reduce the rate of transpiration of the crop, although Kisselbach's work showed that the amount of water required per pound of dry matter was very materially reduced with an increase in the productive capacity of the soil. There is considerable opportunity to increase the amount of available water in the soil by proper methods of soil management related to the control of water secured from rainfall. Beyond these possibilities there is still a chance to select a crop adapted to the water relationships that obtain. When the cost of managing the water supply in the soil reaches a certain point, in any given case, there may be opportunity for choice between crops in which the one best adapted to the soil without further expenditure to regulate the water supply may be selected. Ordinarily, the farmer finds one of his most effective means of increasing yields to be some system of artificial drainage, which has for its primary purpose the control of the water supply in the soil and which is effective as a means of preventing injury from drought as well as from excessive rainfall.

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CHAPTER IV

ORIGIN AND CLASSIFICATION OF SOILS

SOIL is the residue left behind in the disintegration and decomposition of rocks, mixed with varying amounts of plant and animal refuse. If the processes in operation are largely physical, as may be the case in arid regions, the soil will resemble the parent rock quite closely both in its chemical and mineralogical composition, the differences being chiefly a matter of fineness of division. If, in addition, the rock particles have been subjected to the solvent and leaching action of water containing carbonic and other acids and various salts in solution, such as occurs in humid regions, the soil may become largely an accumulation of finely divided, relatively insoluble, mineral residues which bear little chemical or mineralogical resemblance to the original rocks. With the extension of the time element during which the physical and chemical processes continue to be in operation and the biological agencies become increasingly active, there is a tendency toward the production of a more or less uniform soil product no matter what the original rock may have been.

SIMILARITY OF COMPOSITION OF SOILS

The tendency of mineral soils to be similar in chemical composition, irrespective of their source of origin, is very nicely shown in the following table the contents of which were chosen from Bennett's compilation of soil analyses. Four series of soils are represented, the original rocks from which the series were derived being granite, shale, sandstone and limestone, respectively.

TABLE VIII

SIMILARITY OF CHEMICAL COMPOSITION OF SOILS * (BENNETT)

Derived from Widely Different Rocks

Original Rock	Granite	Shale	Sandstone	Limestone
SiO_2	66.49	86.96	74.33	79.35
Al_2O_3	17.11	4.86	11.00	8.89
Fe_2O_3	7.43	2.86	4.64	4.44
MgO	0.31	0.43	0.69	0.39
CaO	0.36	0.71	1.13	0.63
Na_2O	0.16	1.07	1.53	0.24
K_2O	0.62	0.91	1.57	0.67
P_2O_5	0.20	0.07	0.16	0.18
Series	Cecil	Cherokee	Penn	Decatur
Texture	Clay	Silt loam	Silt loam	Clay loam
Sample depth (in.)	0–6	0–6	0–9	0–4

* The range in composition of soils from any one class of rocks is often greater than that of soils derived from different classes of rocks.

CHEMICAL COMPOSITION OF SEVERAL CLASSES OF ROCKS

Consideration of the average analyses of the several classes of rocks, as given by Clarke, indicates that the original rocks, from which the above soils were produced, must have varied considerably more in their chemical composition than did the soils which were derived from them. Of these four classes the greatest variations are found between igneous rocks and limestones. In the formation of soil from the latter class of rocks, all of the carbonates may be eventually leached away with the result that the soil is largely an accumulation of impurities.

To a certain extent what has been said concerning the similarity in chemical composition of mineral soils holds true also with regard to their physical and biological composition. All of the agencies acting on rocks to produce soils tend to effect a reduction in the sizes of the particles. All

TABLE IX

PERCENTAGE CHEMICAL COMPOSITION OF ROCKS (CLARKE)

Oxides	Igneous	Shales	Sandstones	Limestones
SiO_2	59.83	58.10	78.33	5.19
Al_2O_3	14.98	15.40	4.77	0.81
Fe_2O_3	2.65	4.02	1.07	0.54
FeO	3.46	2.15	0.30	.
MgO	3.81	2.44	1.16	7.89
CaO	4.84	3.11	5.50	42.57
Na_2O	3.36	1.30	0.45	0.05
K_2O	2.99	3.24	1.31	0.33
CO_2	0.48	2.63	5.03	41.54
P_2O_5	0.29	0.17	0.08	0.04
SO_3		0.64	0.07	0.05

soils, therefore, are continually being reduced to a finer state of division. These fine particles of soil are distributed by wind and water and their biological population is carried with them with the result that soils tend also to have a common microscopic flòra.

DIFFERENCES IN THE COMPOSITION OF SOILS

Notwithstanding the tendency in the direction of uniformity, the differences in soils at any given time are many. Some of these are apparent to even the casual observer. Others are brought to light only with more careful laboratory study. These differences are physical, chemical and biological. They are reflected in the adaptability of soils to various crops, or in their productivity for some given crop. It will be recalled, however, that crop growth and distribution are determined by the interaction of several groups of factors of which the soil group is only one. These other factors not only affect the crop directly, but also indirectly in their influence on the properties of the soil. There is the further complication in the fact that soils vary within wide limits as to age, and all degrees of degradation of soil par-

ticles will therefore be found depending upon the time factor. A good discussion of the factors involved in reducing rocks to soil is given by Merrill.

SOIL SURVEYS

Soil surveys have for their purpose the classification of soils according to some scheme which will have an agricultural significance. The more recent tendencies in survey methods are in the direction of considering the soil as it now exists, the result of agencies of formation and the climatic conditions to which the soil material has been subjected. Coordinate with soil surveys are the geological and climatological surveys which are under the direction of separate governmental agencies.

CLASSIFICATION OF SOILS

In the classification of soils by survey methods an attempt is made to arrange them in groups that have in common certain physical properties which can be rather easily recognized and differentiated in the field. Soils show considerable variation in the size and arrangement of their constituent particles and in the color of the surface and of the several zones of the soil profile. Certain very simple chemical tests are usable in the field by which the content of carbonates or the degree of acidity can be estimated. The natural vegetation is also more or less of a reflection of the physical and chemical properties of the soil as they affect the nature of the soil solution with which the roots of plants are in contact in any given climatic environment.

The soil survey worker recognizes that the explanations of the differences in soils noted in the field or discovered in the laboratory are to be found in the original rocks from which the soils were derived, the physical, chemical and biological agencies operating in their formation and location, the climatic influences which have surrounded them and the length of time which has elapsed since the soils became located in

their present position. For this reason soils of widely different origin are not grouped together even though they may bear a very close superficial resemblance to each other. The survey worker anticipates that important differences in the properties of such soils will subsequently be discovered by more elaborate laboratory tests.

SOIL PROVINCES

Three terms which early came into use in the classification of soils by the Bureau of Soils of the United States Department of Agriculture are province, series and type. Gradually these terms have come to have more and more specific meanings so that they may now be defined as follows:

Province refers to a large land area in which either the mode or the source of origin, or both, of the soil have been quite similar throughout. Thus the Glacial and Loessial Province of the Bureau of Soils includes the entire land area in the United States over which the glacial processes were most important in the formation of the original soil. The loess soils are associated with the glacial soils by reason of the theory that these wind-blown deposits had their origin in glacial dust. The Limestone Valleys and Uplands Province soils have a common source of origin in limestone rock. The word region is substituted for province in those areas in which the survey has not been extended sufficiently to permit of classification according to any well-defined and common mode or source of origin. The climatic factor is recognized in part as, for example, in the region known as the Arid Southwest.

THE SOIL SERIES

Series refers to a grouping of soils within a province all the units of which have in addition to a similar mode and source of origin, similarity in range as to depth, color and structure of the surface soil and of the several horizons of

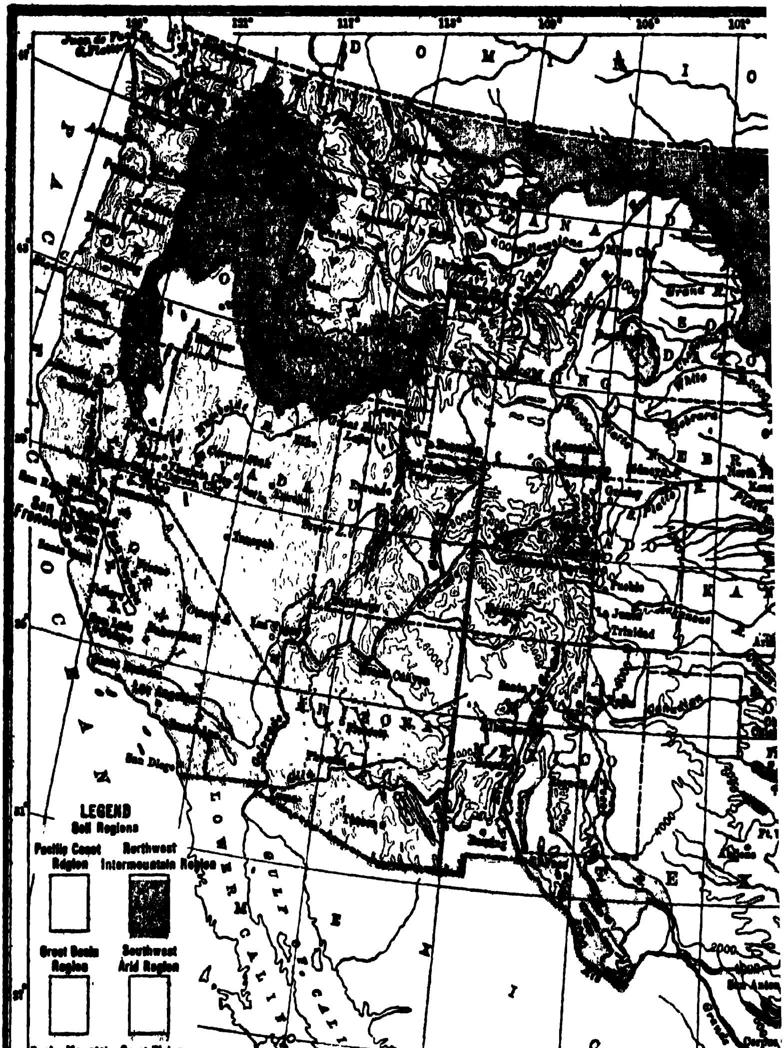

Fig. 4.—"Province refers to a large land area in which either the mode or the s
is substituted for province in those areas in which the survey has not been
mode or source of origin." Map from Bul. 96, Bureau of Soils, U. S. D. A.

the subsoil; in topography; in drainage; in content of carbonates or in degree of acidity. The name applied to the series is that of the location in which it was first recognized and mapped separately. The soils grouped under each series are limited to those which meet the specifications as finally agreed upon by the survey workers. The Miami Series of the Bureau of Soils refers to a group of soils which was first definitely recognized as such in the watershed of the Great Miami River. Being in the Glacial and Loessial Province the mode of origin is defined in this case by the first part of the province name. The source of origin was largely the underlying limestone, mixed with varying amounts of igneous material carried by the glacier from farther north. The soil is defined as being of a gray brown color with a mottled yellow and gray subsoil. The topography is given as gently rolling and the drainage as fair.

Similarly, Dekalb Series refers to a group of soils in the Appalachian Mountain and Plateau Province the members of which are of residual origin; are derived from sandstone and shale: have a yellowish-brown surface soil and a yellow subsoil which contains fragments of the parent rocks. The topography is defined as hilly and the drainage as very

VARIATIONS IN SOME CHARACTERISTICS OF FOUR IMPORTANT SOIL SERIES

Soil Characteristics	1	2	3	4
Mode of origin	Glacial	Glacial	Glacial	Residual
Source of origin	Limestone	Limestone	Sandstone and shale	Sandstone and shale
Color of soil	Gray brown	Black	Gray brown	Gray brown
Color of subsoil	Yellow and gray	Blue, gray and yellow	Yellow and gray	Brown
Reaction	Not acid	Not acid	Acid	Acid
Topography	Gently rolling	Level	Gently rolling	Very rolling
Drainage	Fair	Poor	Fair	Good
Series name	Miami	Clyde	Volusia	Dekalb

good. This series was first recognized and mapped separately in Dekalb County, Alabama. Recognition is given in the different series to other groups of characteristics that are sufficiently well defined and the soils of which cover large enough areas to justify separate classification.

The variations in soils which are used as a basis for their classification into series is illustrated at the bottom of page 31.

It is evident that differences in color, in mode or source of origin, or in other respects, may be sufficient to warrant separation of soils into series.

THE SOIL TYPE

The unit of soil classification is the type. The series are divided into types by the Bureau of Soils on the basis of texture. Thus the Miami Series includes Miami loam, Miami clay, Miami sand and other types which represent various percentage mixtures of the different sized particles of soil. By definition a total of at least 12 types is possible in any series providing there is sufficient variation and range in texture in the soil included in the series, although all the possible variations in texture are seldom realized in a given series.

NATIONAL AND STATE SURVEYS

Fortunately in the United States, the Federal Bureau of Soils cooperating with the several states has been able to standardize the methods and nomenclature of soil classification. The unit of the soil survey is the county. In some states a preliminary reconnaissance survey has been made followed by more detailed county surveys. As would be expected, the survey is never complete for the reason that continued study of the problem makes re-survey on the basis of a better understanding of the soil relationships desirable.

The soil survey is of particular significance in the earlier stages of the agriculture of any state or nation. As farming

becomes more intensified the soil is modified by the farmer to suit his needs. Original differences in soils sufficient to permit of their being classed in separate series may be almost entirely overcome. Thus the chemical composition of soils may be changed materially through the addition of fertilizers and the growth of clover. The soil reaction may

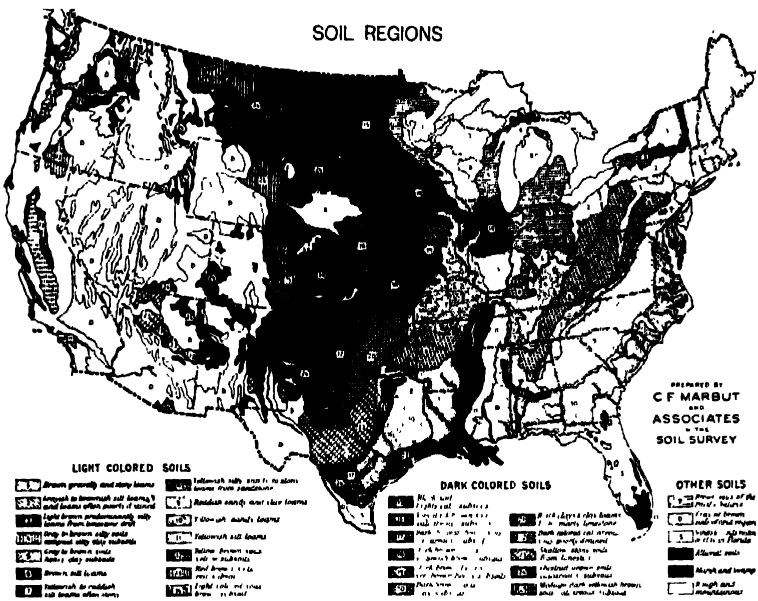

Fig. 5.—"The more recent tendencies in survey methods are in the direction of considering the soil as it now exists, the result of agencies of formation and of the climatic conditions to which the soil has been subjected." Map from Yearbook of U. S. D. A. for 1921.

be controlled through the use of sulphur and limestone. Certain physical properties of soils can be masked by the use of tile or by increasing their content of organic matter. Even the climatic factors which indirectly affect the soil may be partially regulated by irrigation and drainage.

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CHAPTER V

CHEMICAL COMPOSITION OF SOILS

The rocks from which soils are formed differ fundamentally in their mineralogical and therefore in their chemical composition. Limestone may be almost pure carbonate of calcium and magnesium. Granite is composed largely of quartz, orthoclase, and plagioclase with smaller amounts of hornblende and mica. Other types of rocks are differently constituted. In the process of soil formation these minerals undergo decomposition, but at any given time all stages in the process from the original undecomposed mineral to the ultimate products of decomposition may be found in the soil. It would be expected, therefore, that a mineralogical analysis of a soil would provide a clue to the source of origin of the particles in the soil.

MINERALOGICAL ANALYSIS OF SOILS

Notwithstanding the great differences in mineral composition of rocks it is rather surprising to find that most of the common rock-forming minerals are rather generally distributed in soils. This is well shown in the work of McCaughey and William, who examined 25 samples of soil representing as many different series recognized by the Bureau of Soils and found the following mineral distribution:

TABLE X

THE DISTRIBUTION OF MINERALS IN SOILS (MCCAUGHEY)

Twenty-five Soils Typical of as Many Series

Mineral	Present	Abundant	Oxides Contained
Quartz	25	25	Si
Hornblende	23	12	Ca–Mg–Fe–Si
Orthoclase	20	14	K–Al–Si
Microcline	20	10	K–Al–Si
Epidote	24	8	Ca–Al–Si
Biotite	21	8	K–Mg–Fe–Al–Si–H
Muscovite	20	6	K–Al–Si–H
Zircon	22	1	Zr–Si
Chlorite	21	2	Mg–Fe–Al–Si–H
Tourmaline	21	1	Na–Al–B–Si–H
Rutile	17	0	Ti
Plagioclase	13	5	Na–Ca–Al–Si
Apatite	12	0	Ca–P–(F–Cl)

EFFECT OF WEATHERING ON SOILS

In the processes of weathering and leaching in humid climates, the soluble compounds are removed in the drainage water while relatively insoluble residues accumulate to form soil. Thus a soil of limestone origin may contain no carbonates. A soil of sandstone origin may differ very little in chemical composition from that of the original rock. A soil of granitic origin tends to lose its bases in the form of carbonates. As a result, silicon, aluminum and iron, in the form of oxides or hydrated silicates with relatively small percentages of the basic elements calcium, magnesium, sodium, and potassium, tend to constitute the major portion of the soil. However, no two soils are ever exactly alike in their chemical composition, since their rock and mineral origin and the combinations of forces operating in their formation and alteration, including the element of time, are never identical.

CHEMICAL ANALYSES OF SOILS

Some idea of the variation in chemical composition of soils may be secured by a study of the analyses of 126 samples of soil subjected to chemical examination by Ames and Gaither. These samples were selected from as many different points in Ohio and represent considerable variation as to mode and source of origin. Some of them are glaciated and others non-glaciated. Some are derived from mixed igneous and sedimentary rock while others have been derived largely from limestone or from sandstone and shale. The following table shows the highest and lowest quantities of each element found in these analyses:

TABLE XI

VARIATION IN CHEMICAL COMPOSITION OF 126 OHIO SOILS (AMES)

Pounds of Elements per Two Million of Surface Soil

Element	Maximum	Minimum
Silicon	787,000	500,000
Aluminium	184,000	45,000
Iron	89,400	21,000
Calcium	132,000	3,500
Potassium	55,800	22,600
Magnesium	55,600	5,240
Nitrogen	16,640	1,348
Phosphorus	6,000	500
Sulphur	1,000	400

Mucks and peats excluded from table

The amounts of silicon, aluminium, iron and potassium are relatively high in both columns. The elements sulphur, phosphorus, nitrogen, calcium and magnesium are present in only very small percentages in the second column. Keeping in mind the chemical requirements of plants as indicated by their analyses, it would seem logical to expect that the latter group comprises those elements which are most likely

to be present in too small amounts in available forms, in poorly managed soils, to satisfy the requirements of rapidly growing crops.

SOME EXCEPTIONAL SOILS CHEMICALLY

Certain soils have been found which are exceptional in their chemical composition. Beach sands, for example, have been shown to contain as much as 98 per cent and more of silica, which limits the amounts of other soil compounds to very small percentages. The phosphorus content of the soils of the Trenton area in Kentucky are reported by Averitt to average 9400 pounds per two million pounds of soil. In no case was the amount present less than 2600 pounds and in certain cases the amount found was as high as 23,000 pounds per two million of soil. The sulphur content of certain Oregon soils has been reported to be as low as 0.015 per cent. Virgin soils of limestone origin are frequently found to contain sufficient calcium carbonate to effervesce copiously on the addition of hydrochloric acid. Some unproductive black soils reported by Conner and Abbott were found to have a nitrogen content of nearly 4 per cent and a potassium content of only 0.16 per cent. A good review of our knowledge of the chemical composition of soils from various sources is given by Hopkins.

CHEMICAL COMPOSITION OF SUBSOILS

While analyses of soils are commonly reported in terms of the number of pounds of each element in two million pounds of surface soil, an amount supposed to represent the plow depth of an acre of soil, it is a well-known fact that the subsoil contains additional amounts of these same elements which may be of use to plants. In general it may be said that the nitrogen, phosphorus, and sulphur are concentrated in the surface soil. Potassium, iron and aluminium are more abundant usually in the subsoil. Where

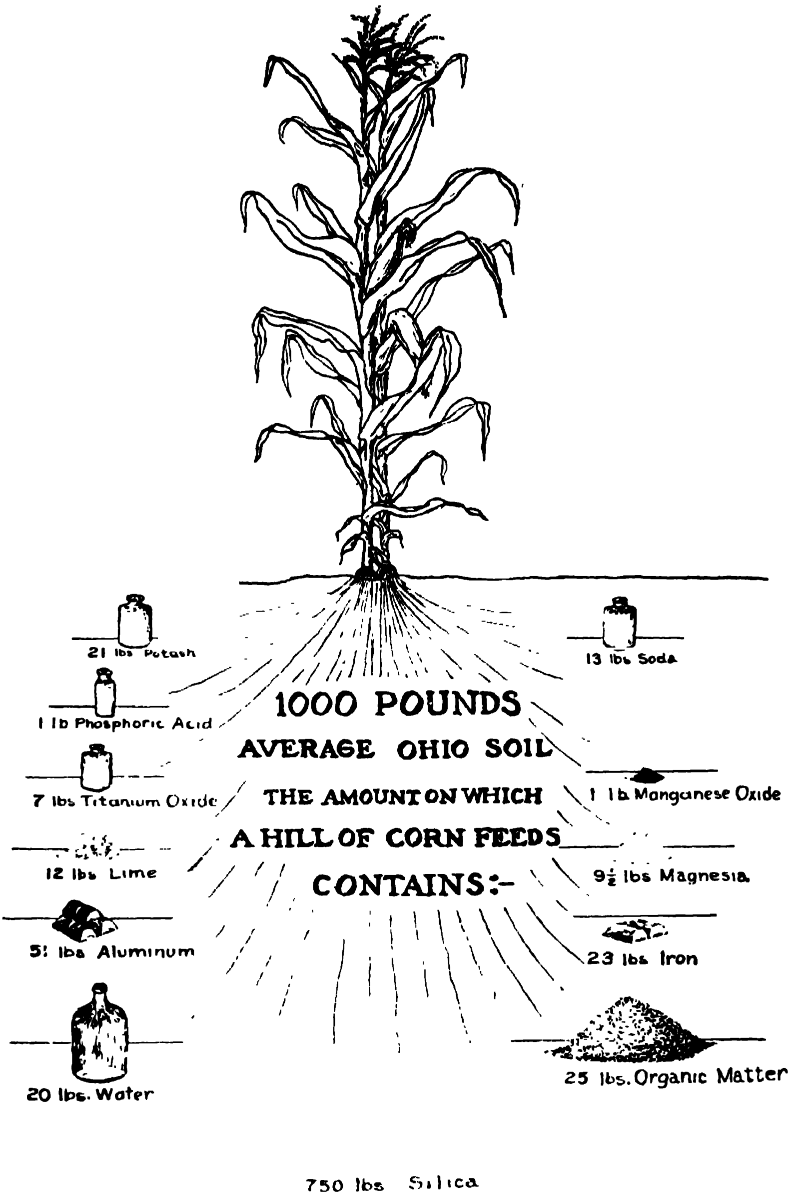

FIG. 6 "Chemical content of a 1000 pounds of average Ohio soil."

soils are of limestone origin, it is quite common to find that the surface soil is acid while the subsoil contains an abundance of carbonates.

RARE ELEMENTS IN SOILS

Robinson has reported that soils contain varying amounts of manganese, titanium, chromium, vanadium, zirconium, molybdenum, nickel, cobalt, barium, strontium, lithium, rubidium and often traces of other elements, depending upon their origin. Of these, manganese is the only one which has been credited with any function in plants, but its status in this connection is not well established. These elements may be disregarded until such time as additional evidence may be presented which would make any of them appear to have a positive effect on plants.

METHODS OF CHEMICAL ANALYSIS OF SOILS

Chemical analysis of a soil for total contents of the several constituent elements is of little value as a guide to its immediate productive capacity. The early recognition of this fact led chemists to attempt to determine the amounts of the essential elements which were present in available forms. In doing this, use was made of dilute solutions of citric, oxalic, nitric and carbonic acids as soil solvents. Later the American Association of Official Agricultural Chemists adopted hydrochloric acid of sp. gr. 1.115 as the standard soil solvent by the use of which it was hoped to effect a separation of that part of the total supply of essential elements which might be assumed to have a value for plant use, with good soil management, in any reasonable length of time.

Most of these methods of extraction have been of value in a comparative way when employed by chemists in the study of series of soils. Used in connection with field observations and greenhouse or plot studies they have provided reliable clues to soil deficiencies. Unfortunately so

many different methods, or modifications of the same method, have been employed that the student of soils finds it difficult to correlate the data now available. Furthermore there has arisen considerable doubt as to whether there was anything to be gained for practical purposes by choosing an empirical method of extraction with some arbitrary solvent over the absolute method of analysis originally employed.

INTERPRETATION OF CHEMICAL ANALYSES OF SOILS

The chemist who adopts the absolute method of analysis recognizes that a considerable percentage of the total amount of each essential element is only very slowly soluble. However, it seems reasonable to believe that if one soil contains twice as much potassium as another soil of the same physical characteristics, the first can be made to yield up more of this element to the plant than the second by the same system of management, although not necessarily in the ratio of two to one. If the content of phosphorus is extremely low as compared to the average soil, it is likely to be more economical to add this element in commercial form than to attempt to make a sufficient amount available from that in the soil. Similarly studies of the total content of nitrogen and of the total carbonates present, or required to bring the soil reaction to the neutral point, are of very definite value in reaching a conclusion as to the practices to be followed in improving the crop-producing capacity of the soil.

SOIL ANALYSES AS A GUIDE TO PRACTICE

If the analysis of a soil is to be of any considerable value as a guide to practice, the sample must be chosen under the direction of someone who appreciates the limitations of the quantitative method of study. Soils vary in their chemical composition from point to point in the same field. Their composition changes with depth. Quite often the subsoil is well supplied with carbonate of lime which may be entirely

absent from the surface soil. For this reason a sample for examination should be chosen to some standard depth and in such a manner as to be representative of the area sampled. By reason of the large amount of analytical work which has been done and the systematic classification of soils by the survey method, it is possible for the man who is familiar with the data available on the subject, if he knows the location of the farm from which the sample was selected, to judge the quality and anticipate the needs of the soil from a more or less superficial examination. Ordinarily the acidity test, the color, the feel of the soil between the thumb and the finger, and a knowledge of the crop or crops to be grown constitute a reliable guide to the system of soil management which will meet the requirements for larger yields.

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CHAPTER VI

SOME BIOLOGICAL PROCESSES IN SOILS

EARLY in the study of soil science it was found that organic matter was an especially important constituent in soils and that their productivity was more or less directly related to the amount of this material in them. Later it was discovered that this organic matter served as a source of food for growth and energy of large numbers of microscopic organisms which inhabited the soil. Still later it was found that certain groups of these organisms had special functions to perform which made them directly essential to the growth and well being of higher plants. Investigators succeeded in isolating members of these groups of organisms, studying them in pure cultures and determining rather definitely their specific requirements. Finally, the conclusion was reached that a systematic classification of soil organisms was desirable if it could be accomplished.

BIOLOGICAL ANALYSIS OF SOILS

Preliminary to any systematic classification of soil organisms it has been necessary to study various kinds and qualities of media in order to determine which one or ones are best suited to purposes of isolation of organisms from the soil. Investigation has shown that no medium can be selected which will meet the requirements of all the species of organisms which inhabit the soil. Consequently the medium ordinarily used is one which will yield the largest number of colonies on a bacterial plate per unit of soil. The medium suggested by Conn for this purpose is made up as follows:

MEDIUM FOR BACTERIAL COUNTS IN SOILS (CONN)

Distilled water	1000 c.c	Magnesium sulphate. . ..	0 2 gr
Agar agar . ..	12 gr.	Calcium chloride	0 1 gr.
Sodium asparagmate	1 gr.	Potassium chloride. ..	0 1 gr.
Dextrose .	1 gr	Ferric chloride . ..	Trace

The method employed for plating the organisms in the soil for purposes of study is somewhat as follows: A known weight of soil, usually 25 grams, is placed in a large flask containing 500 cubic centimeters or some other known quantity of sterile water. After thorough shaking, an aliquot of perhaps 25 cubic centimeters is removed and placed in a second flask containing the same amount of water as the first. The process is continued through several flasks until sufficient dilution of the soil and its associated organisms has been reached so that 1 cubic centimeter of the suspension, mixed with liquid agar or gelatin and spread over a Petri dish will show, after a period of incubation, a development of from 25 to 75 colonies each of which is assumed to have been the product of a single organism.

By such a method of counting it has been shown that the normal soil contains from one to ten million living organisms per gram in addition to those, some of them known and others unknown, which require for isolation the use of selective media suited to their special needs or which must be incubated under anaerobic conditions. Thus the ordinary counts of soil organisms do not include the nodule bacteria of legumes, the non-symbiotic nitrogen fixing organisms, the nitrite and nitrate formers, the fungi, nor any of the anaerobes. Conn has suggested a preliminary classification of the organisms isolated by the above method as follows:

CLASSIFICATION OF THE SOIL FLORA—CONN

Gelatin Plates Inoculated with Soil

Aerobic Incubation

I From 5 to 10 per cent spore formers, B subtilis group

II Under 10 per cent short rods with polar flagella; Ps fluorescens group

III From 40 to 75 per cent non-spore forming short rods

IV A few micrococci

V. From 12 to 50 per cent actinomycetes.

CLASSIFICATION ACCORDING TO FUNCTIONS

Liebig, in 1840, was of the opinion that the nitrogen of plants came from the air in the form of ammonia. While that in the plant residues in the soil was thought to be of use to the plant after its liberation as ammonia in the process of decay, resulting from the activities of soil organisms, the supplemental source of nitrogen to take the place of that removed in crops, or lost from the soil by other means, was thought to be the ammonia dissolved in the rainwater and brought back to the soil by this means. It was later shown by Lawes and Gilbert that the total quantity of nitrogen in combined forms in the rainfall at Rothamsted averaged only from 3 to 5 pounds yearly per acre, an amount entirely too small to compensate for the losses in crops and drainage.

It was finally shown that the nitrogen of all plants, with the exception of legumes, is secured from the organic residues in the soil and is made available through the action of decay organisms. More detailed study revealed the fact that at least three separate groups of organisms are concerned with the change of nitrogen from the protein to a final nitrate form. One group has to do with the production of ammonia, a second, nitrous acid and a third, nitrates. The conclusion was also reached that most crop plants require their nitrogen in the nitrate form, so that the process of nitrification has to be completed before the nitrogen is usable to them

THE REQUIREMENTS FOR NITRIFICATION

A considerable number of factors were found to be involved in determining the rate at which nitrogen in the form of organic residues in the soil will be changed to nitrates. The recentness of origin of the organic matter, its ratio of carbon to nitrogen, the temperature, water content and reaction of the soil are some of the most important. The average soil contains approximately 3500 pounds of nitro-

gen per acre to plow depth. A 100-bushel corn crop requires not to exceed 150 pounds in the nitrate form. Yet it is seldom, if ever, possible to produce this much corn per acre unless the nitrogen of the soil has been supplemented by manure or carriers of soluble nitrogen in commercial form. Until the first step in the process of nitrification has been accomplished, viz.: the production of ammonia, the other steps do not take place. Apparently the organic residues which accumulate in the soil are such as do not readily decay and their nitrogen is changed to ammonia only very slowly. On the other hand, when manure or clover residues are plowed under a considerable portion of this organic nitrogen is changed to ammonia in a relatively short time and the nitrification process goes on to completion.

FIG. 7.—"In the absence of combined nitrogen in the soil, legumes are able to secure sufficient of this element from the soil air to satisfy all of their requirements through the aid of the bacteria in the nodules on their roots."

NITROGEN FIXATION BY LEGUME ORGANISMS

It was early recognized that if the nitrogen in the organic residues in the soil was supplemented only by that which came down in combined form in the rainfall, the continued removal of crops would soon result in the exhaustion of this element from the soil. The good effects of legumes on the other crops in the rotation had long been known. The

presence of nodules on their roots was also known and some study had been made of their nature and content. Attempts were made to determine whether the quantity of nitrogen in the soil was increased by growing legumes. The early experiments of Lawes and Gilbert as well as those of other workers were unsuccessful since, in an attempt to secure greater accuracy, the soil was ignited to drive off all traces of nitrogen which incidentally also destroyed all the soil bacteria. In 1886, Hellriegel and Wilfarth finally proved that the nitrogen of legumes may be secured from the air provided the necessary nodule bacteria are present in the soil. The following table shows the results of one of their experiments in which lupins were grown in nitrogen-free sand in pots, part of which were watered with distilled water and the remaining ones with a solution secured by extracting with water a soil on which lupins had previously been grown successfully:

TABLE XII

NITROGEN FIXATION WITH LUPINS IN NITROGEN-FREE SAND

One of Hellriegel and Wilfarth's Experiments

Pot No.	Dry Weight of Lupins, Grams	Nitrogen Content, Grams	Treatment
3	44 73	1 099	Soil solution
4	45 63	1 156	" "
5	44 68	1 194	" "
6	42 15	1 337	" "
9	0 93	0 011	Distilled water
10	0 80	0 013	" "
11	0 92	0 013	" "
12	1 02	0 013	" "

The only possible source of the nitrogen in the plants grown in these experiments was the air. A considerable amount of data is now available which shows that in the absence of combined nitrogen in the soil, legumes are able

to secure sufficient of this element from the soil air to satisfy all of their requirements through the aid of the bacteria in the nodules on their roots. The soil requirements of the nodule organisms are apparently quite similar to those of the legumes with which they are associated.

NON-SYMBIOTIC NITROGEN FIXATION

In addition to the nodule bacteria, Bacillus radicicola, there are at least two other groups of nitrogen-fixing bacteria which inhabit the soil. The latter groups are not associated with crop plants but function independently of them in the soil. The most important of these has been given the generic name of Azotobacter, of which a number of species have been identified. These bacteria have been found to be rather generally distributed in soils. Under suitable conditions of growth in the soil it has been shown that as much as 200 pounds of nitrogen per two million pounds of soil may be accumulated by them from atmospheric sources in three weeks' time. Optimum conditions for the fixation of nitrogen include the presence of adequate amounts of available carbohydrates, available phosphates, carbonate of lime and good aeration.

Another group of non-symbiotic nitrogen-fixing organisms which appears to be a variety of the common anaerobic butyric acid bacillus, although usually considered as a separate species, has been given the species name of Clostridium pastorianum. These bacteria are able to accumulate atmospheric nitrogen under anaerobic conditions. They also seem to thrive in fairly acid solutions and are believed to play a relatively more prominent part in nitrogen fixation in acid soils than do the Azotobacter.

It is apparent, therefore, that the fixation of atmospheric nitrogen takes place in soils even in the absence of legumes. While the nodule bacteria are perhaps more efficient than the non-symbiotic groups they do not function to any considerable extent except as a legume crop is being grown. The

non-symbiotic bacteria, on the other hand, are believed to be more or less continuously at work in their capacity as nitrogen-fixing agents, assuming suitable conditions in the soil. Some interesting data on nitrogen accumulation in soils, under conditions in which it would appear that most of it must have been accomplished through the agencies of non-symbiotic groups of bacteria, are given by Hall. In this investigation a study was made of the increase in the nitrogen content of the soil in two plots of land at Rothamsted which were allowed to run wild for a period of twenty years. Samples of soil were selected from these plots in 1881–3 and again in 1904 with the following analytical results:

TABLE XIII

NITROGEN ACCUMULATION IN SOILS OF UNDISTURBED AREAS (HALL)

Pounds per Acre at Various Depths

Field	1881–83	1904	Gain
Broadbalk: *			
First 9 inches	2924	3920	996
Second 9 inches	1898	2579	681
Third 9 inches	1569	2265	696
Geescroft: †			
First 9 inches	2219	3537	618
Second 9 inches	1995	2238	243
Third 9 inches	1612	1760	148

* Legumes 25.31 per cent of vegetation in 1904

† Legumes 0.43 per cent of vegetation in 1904

The nitrogen accumulation in the Geescroft field occurred in the almost entire absence of wild legumes. The conclusion was drawn by Hall that non-symbiotic fixation was responsible for most of the gain in nitrogen in this case.

NITRIFICATION OF LEGUME RESIDUES

The nitrogen secured from the air, by the nodule bacteria, is not available to the non-leguminous crops until it has undergone the process of nitrification. The

value of the legume crop to the following crops is determined by the amount of highly nitrogenous residue left behind in its roots and stubble, or returned in the manure produced by feeding it, and the rate at which this nitrogen can be changed to the nitrate form. Lyon has shown that the good effects of the clover crop on the following crop may be explained by the more rapid rate of nitrification of clover residues, as well as on the basis of the increased amount of nitrogen stored in the soil as a result of the growth of the legume crop. In fact it is reasonable to suppose that if the clover secured any considerable part of its nitrogen from the soil, the increase of this element in the soil resulting from its growth must be quite limited, since a large part of the total nitrogen contained in the clover is removed from the field in the harvested crop.

DECOMPOSITION OF SOIL ORGANIC MATTER

The element nitrogen is of such importance in soil economy that it merits special consideration. However, nitrogen is only one of the constituent elements contained in plant residues. The other elements are similarly released from organic combinations in the form of oxidation products. Chief among these is carbon, the central element in all organic matter. In the process of decomposition of proteins, starches, sugars and cellulose in soils, the carbon is finally liberated into the atmosphere, largely as carbon dioxide, in which form it is again useful to the plant in the construction of new material. A large number of intermediate products are formed of which the various amino acids and the acids and alcohols of the fatty acid series may be mentioned. At any given time a certain portion of the organic matter in soils is in only a partially oxidized state. This material, when its origin can no longer be determined, is usually spoken of collectively as "humus." In the absence of cultivation these humus compounds tend to accumulate so that virgin soils are usually well supplied with them. Whenever such

soils are farmed the rate of destruction of the humus is increased and the carbon and other elements are more rapidly liberated in the form of their final oxidation products.

AEROBIC AND ANAEROBIC DECOMPOSITION

The soil bacteria comprise aerobic, anaerobic and facultative groups which are associated with each other in their activities. The aerobes require free oxygen for their life processes while the anaerobes secure this element from sugar and other compounds rich in combined oxygen. In the manure pile anaerobic conditions are maintained by preference since otherwise the rate of oxidation becomes too rapid and "fire fanging" occurs. In the soil, conditions are more largely aerobic and complete oxidation is slowly effected. The final decomposition products are water, carbon dioxide, nitrates and other compounds in a similar state of oxidation. However, the processes by which this final result is accomplished are by no means simple, both aerobic and anaerobic bacteria being involved. If for any reason the conditions in the soil become very unfavorable for aerobic bacteria, such oxidation products as nitrates and sulphates may be reduced with the formation of free nitrogen and sulphides respectively. This may occur if the soil remains filled with water for any considerable length of time or following heavy applications of manure, straw or green manures.

OTHER EFFECTS OF BACTERIAL ACTION IN SOILS

Not only nitrogen and carbon, but also the mineral elements contained in the organic residues in the soil, will be liberated for crop use in the process of decay. The amounts of these mineral elements thus made available, compared to the amount of nitrate nitrogen produced, will be more or less in proportion to the ratios of these elements to nitrogen in the organic matter. As the organic matter is decomposed, any excess of acid over base may have opportunity to act

on the previously undissolved soil minerals with the consequent liberation of additional amounts of the several nutrient mineral elements. Hopkins and Whiting calculated that, if all of the nitrogen needed for the growth of a 100-bushel corn crop acted on phosphate rock while in the acid form, enough phosphorus would be dissolved to satisfy the requirements of seven such crops. Undoubtedly such acids will react for the most part with silicates and limestone and as a result potassium, calcium and magnesium as well as phosphorus will be changed to soluble forms.

SOIL CONDITIONS FAVORING DESIRABLE BACTERIAL PROCESSES

In general, the conditions in the soil are favorable for most desirable bacterial activities when the soil solution approaches the neutral point, when it contains an adequate supply of mineral nutrients, when the soil is fairly well supplied with fresh crop residues, particularly of the leguminous type, or with well-decomposed manure and the tilth and drainage of the soil are such as to provide aeration. In addition there are certain temperature and moisture requirements to be met. However, no matter what the conditions in the soil may be, bacterial activities continue. For example, denitrification may occur if the soil is saturated with water. It is for this reason that sulphate of ammonia is substituted for nitrate of soda as a fertilizer for paddy rice. If the soil becomes acid in reaction the production of ammonia may be accomplished more largely by molds and nitrate production may be reduced practically to *nil*. Under such conditions legumes and their associated nodule organisms cease to thrive and Azotobacter may no longer be active. On the other hand such conditions apparently favor Clostridium pastorianum through the agency of which nitrogen fixation continues. Usually those soil practices which are known to favor the growth of the more desirable crops can also be expected to influence favorably most of the bacteria in the soil which have functions to perform in connection with

making the mineral elements and nitrogen in the soil available for these crops.

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CHAPTER VII

SOME PHYSICAL PROPERTIES OF SOILS

THE physical properties of soils are determined largely by the size and arrangement of their constituent particles. It is, therefore, a matter of considerable importance, in studying any given soil, to know the relative percentages of the different sized particles and the manner in which these particles are arranged in the soil as it exists in the field. A sandy soil, for example, may contain a high percentage of large particles as a result of which its internal surface area, as compared to that of a clay soil, is relatively small and the pore spaces much larger. For these reasons sands tend to lose their capillary water by evaporation and their soluble nutrient elements in the drainage water. While these losses are much reduced in clay soils, other problems arise in their management which may be even more serious. Thus unless the individual particles of a clay soil can be brought together into groups, the preparation of a seed bed is a most difficult problem.

MECHANICAL ANALYSIS OF SOILS

A mechanical analysis of a soil has for its purpose the determination of the percentages of the various sized particles which constitute a soil. These particles, particularly when very small, tend to arrange themselves in groups or floccules, which must be broken apart before an analysis can be made. For this purpose the soil is treated with a deflocculating agent, usually a dilute solution of ammonium hydroxide, and the mixture is subjected for the necessary length of time to the action of a mechanical shaker. The

smaller particles are then separated from the larger ones by decantation of the suspended material. Sedimentation and decantation are repeated several times in order to secure complete separation. The suspensions are subjected to the action of a centrifuge the speed of which is so regulated as to throw out all those particles which have a diameter greater than .005 millimeter. By definition the clay separate is made to include all particles whose diameters are less than this, and silt all those particles whose diameters lie between .05 and .005 millimeter. The coarser particles, after drying, are separated by sieves according to sizes. The details of manipulation have been standardized so that different workers can duplicate each other's results fairly accurately.

SOIL SEPARATES

According to the scheme adopted by the Bureau of Soils of the United States Department of Agriculture, the soil particles are divided by mechanical analysis into groups, or separates, having the following range of diameters:

TABLE XIV

SOIL SEPARATES AS DEFINED BY THE BUREAU OF SOILS OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

Name of Separates	Diameter in Millimeters
Fine gravel .	2.00 –1.00
Coarse sand .	1.00 –0.50
Medium sand . .	0.50 –0.25
Fine sand . . .	0.25 –0.10
Very fine sand	0.10 –0.05
Silt . . .	0.05 –0.005
Clay	0.005 and smaller

It will be observed that the first three each decrease as to diameter by 50 per cent, the fourth by 60, the fifth by 50, the sixth by 90, and the last indefinitely. The range in

size of particles in the various separates is not uniform. Some of the outstanding physical characteristics of soils are related to the percentages of different sized particles belonging to the silt and clay groups. In certain of the States the terms silt and clay are used to designate separates of somewhat different dimensions. For example, in the Illinois soil survey, silt is defined as a separate the particles in which may vary from 0.03 to 0.001 millimeter in diameter and clay is made up of particles with a diameter of 0.001 millimeter or less. It is desirable to have the meanings of these terms standardized. Additional terms are needed for other separates into which the silt and clay, particularly the latter, should be broken up.

SOIL CLASSES

The words silt, sand and clay may also refer, when used as adjectives, to soil classes in which the predominating particles are of the size indicated by the separate name employed as the modifying word. According to the Bureau of Soils a silt soil contains 20 per cent or less of clay and 50 per cent or more of silt. The soils of the United States are grouped into 12 classes according to their texture the specifications for which are indicated somewhat in the class name.

SOIL CLASSES OF THE BUREAU OF SOILS

I. Soils containing less than 20 per cent silt and clay
   1. Coarse sand contains 25 per cent or more of fine gravel and coarse sand, and less than 50 per cent of any other separate
   2. Sand contains 25 per cent or more of fine gravel, coarse and medium sand, and less than 50 per cent of fine sand
   3. Fine sand contains 50 per cent or more of fine sand, or less than 25 per cent fine gravel, coarse and medium sand
   4. Very fine sand contains 50 per cent or more of very fine sand

II. Soils containing 20 to 50 per cent of silt and clay
   5. Sandy loam contains 25 per cent or more of fine gravel, coarse or medium sand
   6. Fine sandy loam contains 50 per cent or more of fine sand, or less than 25 per cent fine gravel, coarse and medium sand
   7. Very fine sandy loam contains 50 per cent or more of very fine sand.

III. Soils containing 50 per cent or more of silt and clay.

8. Loam contains less than 20 per cent of clay and less than 50 per cent of silt
9. Silt loam contains less than 20 per cent of clay and 50 per cent or more of silt
10. Clay loam contains 20 to 30 per cent of clay and less than 50 per cent of silt.
11. Silty clay loam contains 20 to 30 per cent of clay and 50 per cent or more of silt
12. Clay contains 30 per cent or more of clay.

SOME COLLOIDAL PROPERTIES OF SOILS

Of recent years there has been a considerable amount of research on the quantity and the nature of the colloidal matter in soils. Since clay is defined as a soil separate the particles of which have a diameter of .005 millimeter or less, the question naturally arises as to what the lower limit of size of these particles may be. Evidently the reduction in size must continue until the molecular state is reached, at which point solution occurs. A molecule of hydrogen is estimated to have a diameter of 0.16 milli-micron and a molecule of chloroform one of about eight times this length. Between the molecular state and the upper limit of size of clay particles is a very wide range in dimensions. As the state of division increases, the combined surface exposed is enormously increased. Surface phenomena which may have been almost negligible in coarse sands are brought into prominence when the soil is made up largely of particles which have been reduced to a very fine state of division and which exist in what is known as the colloidal state. Thus, for example, soils containing a high percentage of colloidal matter may offer very serious competition against the plant for water and mineral nutrients in the soil solution. Similarly, the movement of air and water through such soils may be very much reduced and, as a result, certain difficulties may be encountered in their management.

CRUMB STRUCTURE IN SOILS

The sizes of particles in soils cannot be modified except in a very limited way, by any means in the hands of the farmer, but certain practices may be employed which may very materially affect their arrangement and the working qualities of the soil. Under good management these finely divided particles tend to arrange themselves in what is known as a crumb structure. Working a clay soil while wet has much the same effect on it as occurs with fresh bread when it is rolled between the thumb and finger. By this process the pore spaces are largely eliminated and the particles are brought together in such close proximity as to produce a doughy mass which on drying has many of the characteristics of a clod. In the management of clay soils such a condition is avoided in so far as possible. In sandy soils it may be found desirable to prevent the development of the crumb structure as a means of increasing the water-retaining capacity of the soil as well as improving its working qualities.

TILTH IN SOILS

Good tilth is a condition which is to be sought in all soils. A soil may be said to be in good tilth when with the minimum amount of labor it can be put into condition to grow crops. Four controllable factors are particularly important in this connection. One of these, already mentioned, is the amount of water which the soil contains at the time when it is being worked. A second is the extent to which the freezing and drying processes are given opportunity to function. It is a well-known fact that a soil which is in poor tilth, or which has been broken up in clods tends to become mellow when exposed to the action of frost or heat. Part of this improvement is apparently related to the mechanical effect of these processes and part to the dehydration of the somewhat gelatinous hydrated colloidal materials in the soil. A third

controllable factor is the soil reaction. Lime has been shown to play an important part in the improvement of the tilth of acid soils. On the other hand, alkalies, such as sodium carbonate or the sodium residue of nitrate of soda, tend to deflocculate the soil. The fourth factor, organic

FIG. 8.—"It is a well-known fact that a soil which is in poor tilth or which has been broken up in clods tends to become mellow when exposed to the action of frost or heat." Spring disking of fall plowed land. (Courtesy Oliver Chilled Plow Company.)

matter in the form of plant residues, if present in considerable amounts, tends to mask the physical properties of soils so that even such extremes as clays and sands come to have quite similar properties in so far as tilth or the capacity to produce crops under a given climatic environment are concerned.

RELATION BETWEEN CHEMICAL AND MECHANICAL COMPOSITION OF SOILS

Certain general statements can be made with reference to the relationship between chemical and mechanical composition of soils. For example, Failyer and his associates have shown that the smaller the particles the greater the percentages of phosphorus, potassium and calcium. Hall found that this was also true of aluminium, iron and magnesium. Of considerable significance is the content of silica. If this had its origin in quartz it tends to resist the action of the elements and to form coarse-textured soils. The percentage of silica is therefore quite high in sandy soils. If the source of the silica was silicates the end products of decomposition are the oxides of iron, aluminium and silicon of which the last is apparently removed most rapidly in soluble and colloidal form in the drainage water, leaving the other two oxides behind in increasing ratios.

As the fineness of division increases there is also considerably increased opportunity for the phenomenon of adsorption to operate in the retention of certain of the soil elements, particularly potassium and phosphorus.

PHYSICAL ANALYSIS OF SOILS

The size and arrangement of soil particles has considerable to do with the water and air relationships in soils. They, therefore, affect fundamentally the biological properties of the soil. They also influence the rate of solution of mineral elements and nitrogen as well as the capacity of the soil to retain elements which are supplied in soluble form. It is a well-known fact that the chemical analysis of the soil may show large amounts of mineral constituents and yet the soil may be unproductive if for any reason the arrangement of its particles prevents the adequate circulation of water and air. It is possible, therefore, to determine something of the possibilities of productiveness of a

soil by what might be called physical analysis which takes into consideration these various physical properties of soils and the matter of crop adaptation in relation to them. Unfortunately laboratory studies of physical properties are difficult to interpret since in moving the soil to the laboratory its physical condition is disturbed. However, more attention is being given to such physical properties as water-retaining capacity, pore space, permeability to water and air, plasticity and cohesion. Lyon and Buckman have brought together the most important data on the physical characteristics of soils which are of interest in this connection.

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CHAPTER VIII

SOIL WATER

An important physical property of soils in relation to crop production and distribution is their water-maintaining capacity. In general it may be said that soils tend to maintain fairly constant water contents. It is for this reason that some soils are best adapted to cereal crops and others to potatoes, truck crops or grass. A suggestive preliminary study of this relationship between water-maintaining capacity and crop adaptation was made by Whitney.

WATER-MAINTAINING CAPACITIES OF SOILS

In this study samples of soil were selected to a depth of 1 foot each day during the growing period from fields in which the crops known to be well adapted to the soil and climate were being grown. As a result of this study the following data were obtained:

TABLE XV

Average Per Cent of Water Maintained by Soils Known to be Well Adapted to Crops Indicated

Crop Adapted to Soil	Location, State	Per Cent Water * Maintained
Truck	Maryland	6
Wheat	Maryland	13
Grass	Maryland	18
Light tobacco	Connecticut	7
Heavy tobacco	Pennsylvania	18

* Percentage of dry weight of soil

GRAVITATIONAL WATER IN SOILS

The total capacity of a soil for water is determined by the volume of its pore space which ordinarily amounts to from 30 to 50 per cent of the total volume of the soil as it occurs in the field. Following a heavy rain this pore space may become entirely filled with water to the exclusion of the air. If such conditions obtain over any considerable period of time, injury to the growing crop will be noted. An attempt is ordinarily made in well-managed soils to have the gravitational water carried away at a sufficiently rapid rate to prevent injury and yet not so rapidly as to result in excessive leaching of the soluble nutrient elements from the soil. In the event that this can be accomplished the gravitational water is gradually replaced by a renewed supply of air with marked benefit to crops.

CAPILLARY CAPACITY OF SOILS

Three forces are in operation which tend to separate the water from the soil. These forces are gravity, transpiration

TABLE XVI

Capacity of Soil to Retain Water in Opposition to Gravity (King)

Soil Saturated and Allowed to Drain for 60 Days

Height of Column in Inches	Per Cent of Water Retained *	
	Sandy Loam	Clay Loam
81 84	16 16	21 26
69 72	16 55	31 05
57 60	17 59	31 21
45 48	18 70	31 99
33 36	20 90	32 45
21 24	21 16	34 10
9 12	22 68	35 97
3 6	27 69	37 19

* Percentage of total volume of soil

and evaporation. The percentage of its total capacity for water which a soil will retain in opposition to the pull of gravity is largely determined by its texture and the height of the column above the water table. King presents some data on this point for a sandy loam and a clay loam soil which were placed in cylinders 7 feet in length, saturated with water and allowed to drain for a period of sixty days. The data are given in Table XVI.

WILTING POINT OF PLANTS

After the gravitational water has been removed from a soil, additional losses occur by transpiration and evaporation until, in the absence of renewal by rain or from an underlying water table, equilibrium has been established with the atmosphere. The hygroscopic water remaining in the soil at this point is assumed to be present in the form of extremely thin films over the surface of the soil particles. Sometime before this point of equilibrium has been reached plants growing on the soil will begin to wilt. Briggs and Shantz studied the wilting point of plants in relation to the hygroscopic capacity of soils in a saturated atmosphere and found the ratios indicated in the following table:

TABLE XVII

PER CENT OF WATER IN SOILS AT WILTING POINT OF PLANTS *

Compared to that at Equilibrium with the Atmosphere

Soil Type	Wilting Point	Hygroscopic
Coarse sand	0.9	0.5
Fine sand	2.6	1.5
Sandy loam	4.8	3.5
Fine sandy loam	9.7	6.5
Loam	10.3	7.8
Clay loam	16.3	11.4

* Percentage of dry weight of soil

RATE OF CAPILLARY MOVEMENT OF WATER

As water is lost into the atmosphere from the surface soil, additional water moves upward by capillarity to replace it. If the soil column is in contact with a water table the amount of water which becomes available to the roots of plants by this means may be quite large. Of particular interest in this connection is the rate of movement of capillary water and also the extent to which the roots of plants may

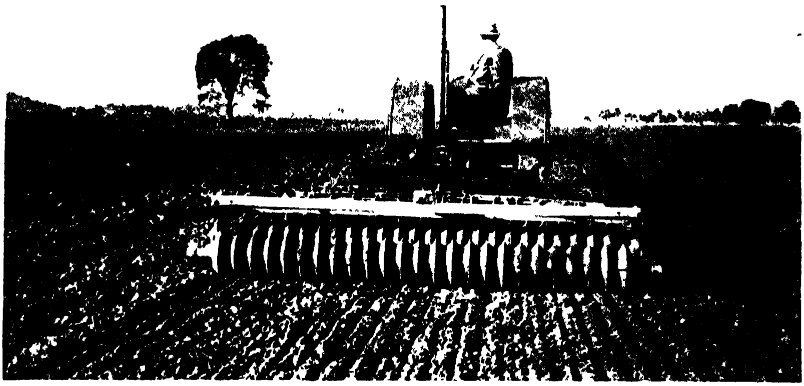

FIG. 9.—"The surface mulch has been recommended as a means of conserving water. . . . Compacting the soil tends to cause a more rapid movement of capillary water." The Cultipacker accomplishes both purposes (Courtesy, International Harvester Company.)

penetrate into a well-drained subsoil in the direction of the water table.

Capillary movement of water is very rapid over a short distance in coarse-textured soils, but the height to which it will rise is quite limited. In clay soils the total rise is greater but the resistance offered to the movement of water is such that the rate is quite slow. The most satisfactory capillary movement is found in medium-textured soils, loams and silt loams, where the rate of movement is quite rapid and the total capillary rise is greatest. An interesting study of this point is given by G. W. Conrey as recorded in Table XVIII.

TABLE XVIII

EFFECT OF TEXTURE ON RATE AND HEIGHT OF CAPILLARY RISE OF WATER IN DRY SOILS

Height of Water in Inches at Periods Indicated

Time	Dunkirk Sand	Wooster Silt Loam	Brookston Clay
½ hour	13.5	7.3	5.4
1 hour	14.3	11.2	8.0
6 hours	16.6	26.0	15.5
12 hours	17.2	35.3	18.5
1 day	18.1	46.4	21.0
3 days	20.3	65.1	24.7
6 days	21.8	78.5	27.3
9 days	23.0	86.3	28.8
18 days	25.3	99.2	33.2

THE SURFACE MULCH

The rate of movement of capillary water is very much reduced if the soil column has been broken and the particles are dry. Under such conditions the movement of water may be almost entirely prevented, particularly if the surface of the soil is a considerable distance above the water table. It is for this reason that the surface mulch has been recommended as a means of conserving water. King studied this problem by placing soil in cylinders at the bottom of which additional water was supplied to replace that lost by evaporation from the surface. The exact height of the cylinders is not given, but ordinarily the soil columns extended about 12 inches above the water level. An example of the results obtained from such a study is given by King as shown in Table XIX.

Conversely, compacting the soil tends to cause a more rapid movement of capillary water. This is particularly true if the soil column is already moist throughout its entire length.

TABLE XIX

EFFECTIVENESS OF THE SOIL MULCH IN CONSERVING WATER

Tons of Water per Acre Lost by Evaporation in 100 Days

	Clay Loam	Black Marsh	Sandy Loam
No mulch	2411	588	741
One inch mulch	1260	355	373
Two inches mulch	979	270	339
Three inches mulch	889	256	287
Four inches mulch	883	252	315

DEPTH TO WHICH ROOTS PENETRATE THE SOIL

It is a well-known fact that the roots of most crop plants tend to grow downward in the soil to considerable depths unless prevented from so doing by some impervious layer of rock or of subsoil or by the presence of a water table. King studied the root development in Wisconsin of some of the common farm crops and found that the roots of corn, wheat, barley and oats, at maturity, had reached a depth of more than four feet. With corn, the soil was filled with roots extending across the intervening space between the rows and to a depth of 2 feet by the time the plants had reached a height of 30 inches. If the water table is under control at a reasonable depth, these roots, when once well-established, may be able to secure sufficient water to satisfy the requirements of the plant even though the surface soil may contain only its hygroscopic capacity.

Plants differ considerably in their root-systems and the extent to which these roots penetrate the subsoil. Those with deep root-systems are the last to suffer from drouth. This fact is taken advantage of in the killing of grass and weeds in the irrigated alfalfa fields of the West. Wet lands, if difficult to drain, are quite commonly given over to pastures and the grasses which develop are largely those whose root-systems are limited in depth. Under such conditions

it is essential that the rainfall be frequent and abundant, or that the land be kept supplied through the summer with drainage water from surrounding higher levels.

LATERAL MOVEMENT OF WATER IN SOILS

The movement of water in soils is largely vertical. The pull of gravity is downward. Loss of water into the atmosphere gives opportunity for capillary rise upward. Because of these up and down tendencies little lateral movement takes place. The lack of lateral movement need not prevent the translocation of salts in solution but it is apparent that the latter would be considerably increased if the former took place to any extent. In the permanent grass plots at Rothamsted the differences in the growth and the nature of the grasses and weeds are very sharply defined at the imaginary lines separating the several plots on which the different fertilizers are applied, although the experiment has been in progress for three-quarters of a century.

OPTIMUM WATER CONTENT OF SOILS

The optimum growth of plants is probably obtained at a water content approximating 60 to 70 per cent of saturation. Greaves found that ammonification and nitrification processes are carried on most rapidly at 60 per cent saturation, while nitrogen fixation by non-symbiotic organisms was most rapid at 70 per cent of the total water capacity of the soil. These may not be the quantities of water which provide optimum working conditions for the soil. Studies have shown that there is a water content at which each soil can be cultivated most effectively and easily. In sandy soils this is at a point which might be considered over wet. Ordinarily this point is at approximately two-thirds saturation. The practical difficulty found is that of meeting the requirements of the variety of soils often present in each field. Furthermore, cultural operations in a field cannot ordinarily be completed in a short enough time to take

advantage of the most suitable amount of water throughout the entire period required.

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CHAPTER IX

SOIL AIR

THE giving off of carbon dioxide is a function of both the leaves and the roots of crop plants. It is necessary, therefore, that there be some process of ventilation of the air in contact with these parts of such plants in order to prevent an accumulation of this respiratory product. The leaves of plants have this accomplished for them through the action of winds and air currents. In the soil the problem is more complicated and at times special attention must be given to the means of renewing the air supply in contact with the roots of crops.

COMPETITION OF AIR AND WATER FOR PORE SPACE

The pore space in a soil, as previously mentioned, amounts to from 30 to 50 per cent of the total volume occupied by the soil. Part of this space is taken up by water and the remainder by air. As the quantity of water is increased a point is finally reached at which the lack of available oxygen, or the accumulation of carbon dioxide, becomes a limiting factor in crop growth. This is perhaps one of the important reasons for the decrease in response per unit of additional increments of water in irrigation experiments. The work of Widtsoe with wheat, for example, furnishes a good illustration of this point. In these investigations the rainfall during the growing season amounted to 13.74 inches. Adding to this the inches of irrigation water supplied, and dividing this into the number of bushels of wheat produced in the several tests gives the following data:

TABLE XX

INCREASES IN YIELD OF WHEAT FROM ADDITIONAL INCREMENTS OF WATER

Nine-Year Averages, Irrigation Studies (Utah)

Water, Acre Inches	Wheat Yields, Bushels per Acre	Bushels of Wheat, Per Inch of Water
18 74	37 81	2 02
21 24	41 54	1 95
23 74	43 53	1 83
28 74	45 71	1 58
38 74	46 16	1 20
48 74	48 55	1 00
63 74	49 38	0 77

The law of diminishing returns is in operation in the above case and the injurious effects of a lack of oxygen and of the accumulation of carbon dioxide come into play.

EFFECT OF AERATION OF CULTURE SOLUTIONS

A somewhat better example of the effect of a failure to renew the air supply of the roots of plants may be found in the work of Hall and his associates in connection with the growing of land plants in culture solutions. Under such conditions these plants are far removed from their natural environment. However, it is probably safe to assume that the effect of the aeration of the culture solutions noted in the accompanying table is not greater relatively than would occur under field conditions if the soil were wet and a similar method of aeration could be put into operation.

Plant roots differ considerably in their aeration requirements. Hall's investigations showed that buckwheat, a plant which grows satisfactorily on somewhat wet and acid soils, is not nearly so sensitive to a lack of aeration of the culture solution as is barley. On the other hand, when the culture solutions were aspirated with carbon dioxide all of the plants, including buckwheat, soon wilted.

TABLE XXI

EFFECT OF AERATION OF CULTURE SOLUTION ON THE GROWTH OF PLANTS

Treatment	Weight in Grams per Plant	
	Barley	Lupins
Non-aerated	1 31	0 83
Continuously aerated	2 12	1 53

EFFECT OF ANAEROBIC CONDITIONS ON SEED GERMINATION

The germination of seeds is also inhibited by anaerobic conditions. A review of the literature on this subject and also of the entire problem of aeration of soils as related to the growth of plants is given by Clements. In this review it is shown that if for any reason there is a reduction in the amount of oxygen or an increase of carbon dioxide beyond the normal, germination is delayed and, with further increase in the concentration of carbon dioxide, is prevented entirely.

TOXIC EXCRETIONS OF PLANTS

A large amount of investigational work has been done in an attempt to explain the causes of unproductivity of soils which have been under cultivation for some years. Of interest in this connection are some publications of the Bureau of Soils of The United States Department of Agriculture and of the Woburn Experimental Farm in England, in which the theory was advanced that plants excrete toxic substances during growth which are particularly harmful to other plants of the same species. The good effects of crop rotation were believed to be partially explained by this theory. The evidence on this subject has also been reviewed by Clements. It indicates that the only excretory product of the roots of plants grown under normal conditions which might have any toxic effect is carbon dioxide. Any organic toxicity which may develop in soils is probably

the result of anaerobic decomposition and with an absence of supplemental oxidation by aerobic bacteria. It is conceivable that a considerable number of reduction compounds

Not aerated Aerated

FIG. 10 Effect of aeration of culture solution on the growth of corn plants

might be produced under certain conditions in soils which, if allowed to accumulate, would not only be toxic to plants but to soil bacteria as well.

THE SIGNIFICANCE OF COLOR IN SOILS

Of particular interest in connection with possible toxicity in soils resulting from insufficient aeration is their color. In well-drained soils the compounds of iron are oxidized to the ferric state as indicated by their red, yellow or brown colors. In the absence of good drainage the subsoil is often of a bluish, gray or mottled color indicating the presence of reduction compounds. Humus soils, formed in swamps, are black or brown in color, depending on the nature of the processes of decomposition as related to the air supply and the presence or absence of carbonate of lime in the leachings from the surrounding higher levels. The presence of ferrous compounds in the subsoil is indicative of reducing conditions unfavorable to the growth of aerobic bacteria and of crop plants. Ferrous sulphate is known to be toxic to plants and is used as a spray for eradicating such plants as mustard and dandelion. It seems quite probable that if the subsoil contains this and similar compounds the development of many species of bacteria and of plant roots will be hindered. Farmers have learned to judge the quality of soils by their color and with considerable accuracy, as might be expected from the relationships indicated above.

THE COMPOSITION OF NORMAL SOIL AIR

Russell and Appleyard studied the composition of the air of the Rothamsted soils in considerable detail. The oxygen content of the surface soil was found to average about 20.60 per cent and the carbon dioxide 0.25 per cent of the total volume as compared to 20.9 and 0.03 respectively for the ordinary atmosphere. The carbon dioxide content fluctuated somewhat throughout the season, depending upon the climatic and soil conditions as affecting the growth of plants. The following table is of interest in this connection:

TABLE XXII

PERCENTAGE COMPOSITION OF THE SOIL AIR THROUGHOUT THE SEASON

Rothamsted—Broadbalk Field—Continuous Wheat

Date	Dunged Plot		Unmanured Plot		Inches Rainfall, Previous 7 Days	Degrees C.	
	CO_2	O_2	CO_2	O_2		Air	Soil
Feb 11	0 55	18 97	0 13	19 86	0 60	8 3	. . .
Mar 13	0 16	20 18	0 21	20 53	0 22	3 9	. . . .
Apr 11	0 65	19 70	0 22	20 64	0 68	1 7	. . . .
May 13	1 15	19 12	0 35	20 53	0 56	10 5	11 1
June 3	0 12	20 56	0 50	20 77	0 35	13 9	17 4
July 11	0 35	20 66	0 29	20 79	0 42	15 0	15 5
Aug 29	0 21	20 70	0 22	20 73	0 24	19 4	18 1
Sept 22	0 17	20 79	0 11	20 83	0 52	14 4	13 3
Oct 6	0 18	20 81	0 16	20 82	0 41	11 1	12 9
Nov 10	0 54	20 72	0 35	20 56	0 21	5 0	6 5
Dec 22	0 34	20 45	0 25	20 35	0 13	2 8	4 5

Turpin believes that the increased concentration of carbon dioxide in the soil during the growing season is fairly definitely correlated with the rate of growth of the plant and that it is in considerable part due to the respiration of the plant roots. There seems to be evidence in favor of this conclusion in the above table. Thus the wheat crop probably began to grow nicely in November, was retarded for a time during the cold weather of December and January, but came on more rapidly in the spring with maximum growing activity and respiration in May.

EFFECT OF EXCESSIVE AERATION

Coarse-textured soils, if well drained, are likely to have their air supply renewed so frequently that the oxidation processes may become excessively rapid. This fact has been noted in the difficulty found in maintaining a sufficient amount of organic matter in sandy soils, particularly those which are under cultivation in warmer latitudes. The

plant residues are oxidized so readily, and the soluble products which are formed are carried away so rapidly in the drainage, that these soils soon lose their productivity. Such soils are highly productive if precautions are taken to renew the organic matter by the use of green manuring crops or otherwise as rapidly as it is destroyed. This is particularly true if the moisture supply can be controlled by some type of irrigation.

MEANS OF CONTROLLING SOIL AERATION

Ordinarily the problem is one of increasing the rate of movement of air through soils to prevent the accumulation of reduction compounds and to remove the carbon dioxide excreted by plants, or resulting from bacterial action. Normally, the change of air is accomplished by its expansion and contraction due to changes in temperature and by its displacement by water with subsequent renewal as the water is lost by drainage, transpiration and evaporation. It is in the absence of the free movement of water, and particularly with the finer textured soils, that the problem becomes serious and measures must be taken to increase the rate of air renewal. Cultivation may be of some value, but artificial drainage and the introduction of large amounts of crop residues are the most effective means of accomplishing the desired result. Something can be done in choosing crops adapted to such a condition in the soil.

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CHAPTER X

THE SOIL SOLUTION

In order to provide optimum conditions for the growth of plants in water cultures, it is necessary to control within somewhat narrow limits the total concentration of the salts in solution, the reaction of the solution and the ratios in which the several ions are present. These requirements are undoubtedly met in productive soils. Unfortunately little is known concerning the exact nature of the soil solution by reason of the difficulties involved in its separation unchanged from the soil. A good review of the methods employed in such work is given by Parker. From his and other investigations some idea of the concentrations of the several ions in soil solutions has been gained. There is, however, a fundamental difference between soil and culture solutions in that in the former case the solution is in contact with the undissolved mineral complex and its rate of renewal from this, as the dissolved elements are removed by crops and in drainage water, is likely to be quite variable depending upon the conditions which obtain.

ALKALI SOILS

In regions in which the rainfall is limited to such amounts that the loss of water through drainage is practically negligible, the substances which have been dissolved from the soil accumulate in the form of soluble salts. Such rain as falls, together with the acids produced in the oxidation of organic compounds containing the elements carbon, nitrogen, sulphur and chlorine, act on the soil minerals with

the formation of salts of the alkalies and alkali earths. Eventually the soil may contain large amounts of carbonates of sodium and potassium, the acid carbonates of calcium and magnesium and the sulphates, chlorides and nitrates of all of these elements.

Harris gives the composition of the resulting "alkali" as determined at several different locations in the United States, as follows:

TABLE XXIII

PERCENTAGE COMPOSITION OF ALKALI FROM DIFFERENT STATES

Salts	Colorado	California	Washington	Montana Crust	Montana Surface, 10 in.	Arizona Crust	Arizona 0–72 in.
KCl	1.61		5.61			1.00	22.10
K_2SO_4		3.95		1.60	21.41		
K_2CO_3			9.73				
Na_2SO_4		25.28		85.57	35.12		
$NaNO_3$	33.07	19.78					
Na_2CO_3		32.58	13.86		7.28		
NaCl	6.61	14.75		0.55		81.15	13.77
Na_2HPO_4		2.25					
$MgSO_4$				8.90	4.06		6.88
$MgCl_2$	12.71					7.71	3.98
$CaCl_2$	17.29					0.25	
$NaHCO_3$			36.72	0.67	22.06	0.28	21.02
$CaSO_4$	21.48		1.87	2.71	10.07	6.61	32.25
$Ca(HCO_3)_2$			16.18				
$Mg(HCO_3)_2$			15.73				
$(NH_4)_2CO_3$		1.41					

ALKALI TOLERANCE OF CROPS

The accumulation of these salts, commonly called alkali, interferes with the growth of plants either by reason of the abnormally high concentration, the alkalinity or the unfavorable ratios in which the soluble ions are present. As would be expected, plants differ considerably in their capacity

to endure alkali. Among the more resistant crops may be mentioned alfalfa, sweet clover, millets, sorghums, rape, barley, rye, sugar beets, asparagus, and cotton. Of the fruit trees the date palm is perhaps the most resistant. As Harris points out, the ability of plants to withstand the effects of alkali is determined not only by the nature of the alkali, but also by its distribution in the soil. Deep-rooted plants thrive best where the alkali is concentrated in the surface soil while shallow-rooted crops may do best when the alkali salts are deeper.

CONTROL OF SOIL ALKALI

Irrigation with an excess of water, which is removed by tile or allowed to run off the surface, is an efficient means of

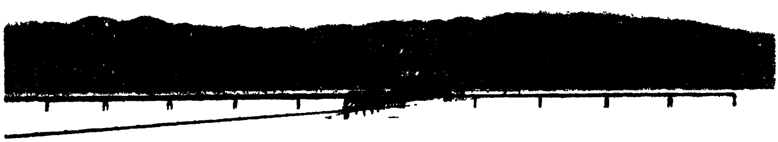

FIG. 11 "In regions in which the rainfall is limited to such amounts that the loss of water through drainage is practically negligible, the substances which have been dissolved from the soil accumulate in the form of soluble salts." (Courtesy of the American Trona Corporation, producers of "Kemfort" potash salts.)

removing soluble salts from soils. This method is not applicable over any very large area of land since as a rule the quantity of irrigation water is limited. If the cause of injury of the alkali is its alkalinity, the application of calcium sulphate is sometimes recommended. Sulphuric acid

and elemental sulphur have also been suggested as neutralizing agents for alkaline soils. Other devices such as scraping the alkali crust from the surface and plowing to greater depths have been employed. The alkali soil problem is much more difficult than that of acid soils although the area over which alkali is a limiting factor is much less than that included in the humid regions where acid soils are the rule.

ACID SOILS

In humid regions the soluble salts which are formed in the decomposition of minerals are gradually removed in the drainage water. Accumulation is therefore prevented. Evidence of this removal is to be found in the immense deposits of common salt, potash salts and limestones which are variously distributed over the earth. As the basic elements are removed, the soil becomes more largely made up of iron, aluminium and silicon in the form of hydrated silicates and oxides. The decay of organic matter in the soil hastens the process. A partial check against these losses is provided when the soil is covered with vegetation which utilizes the mineral nutrients as they are dissolved.

Iron and aluminium being amphoteric, and silicon an acid-forming element, the gradual removal from the soil of the basic ions, sodium, potassium, calcium and magnesium, results in the accumulation of a potentially acid residue. A typical example of an acid silicate residue is found in kaolinite, which may be represented by the formula

$$2H_2O \cdot Al_2O_3 \cdot 2SiO_2.$$

This was derived from orthoclase, having the formula

$$K_2O \cdot Al_2O_3 \cdot 6SiO_2.$$

A loss of silica and a substitution of hydrogen for the potassium has been effected in the decomposition process. Potas-

sium carbonate being soluble in water was gradually leached from the soil. In the more advanced stages of weathering the total amounts of calcium and magnesium are often found to have been reduced to less than 5000 pounds per two million pounds of soil. The contents of sodium and potassium are seldom less than four or five times this amount.

AVIDITY OF SOIL ACIDS

A considerable part of the acidity of soils is potential but not directly injurious to plants. Hydrated silicates are not highly soluble. However, they may serve as competitors of plants for bases in the soil solution. Furthermore, the acids in soils vary in their strength, this being determined by the extent to which they yield up free hydrogen ions to the soil solution. The concentration of hydrogen ions is now ordinarily expressed in terms of pH which is the common logarithm of the reciprocal of the hydrogen ion concentration expressed in terms of normality, the neutral point being represented by pH 7. A solution having a pH of 5, for example, contains 100 times as many free hydrogen ions as pure water while one with a pH of 8 has 10 times as many OH ions as pure water. The pH of soils of humid regions has been found to range from about 4 to 8.

ACID SOILS IN RELATION TO THE GROWTH OF CROPS

Experience has shown that with an increase of acidity in soils, crops having a high lime-requirement, such as sweet clover, alfalfa, lettuce, spinach, beets and many other common crops, are replaced by others which are less sensitive to acid soils conditions. With greater increase in acidity it becomes necessary to substitute less desirable crops until a point is reached at which few of those commonly grown will thrive. Further complications arise from the fact that desirable soil bacteria, particularly those which have to do with nitrogen fixation and nitrification, are also injured by

acid soil conditions with the result that nitrogen economy becomes a more serious problem.

It has also been found that acid soils are injurious to crops and soil organisms in certain indirect ways. Of particular interest in this connection is the work of Hartwell and Pember in which it was shown that soluble aluminium, common to all acid soil solutions, is toxic to plants, in some cases much more than others. It was found that barley and rye were injured in much the same degree by increasing concentrations of acid, but very differently by the presence of aluminium in solution. For this reason, any crop to which aluminium is toxic in dilute concentrations will have difficulty in growing on an acid soil. Barley is a good example of such a crop.

Hoffer has shown that the injury to corn produced by the disease commonly known as "root rot" is associated with the accumulation of aluminium salts in the plant, especially in the nodal tissues.

THE RATIOS OF THE IONS IN THE SOIL SOLUTION

The ratios in which the several ions exist in the soil solution are also important. McCool has shown, for example, that ammonium, magnesium, sodium and potassium ions are each toxic to plants when supplied singly as salts to culture solutions. This toxicity may be overcome by the addition of other ions of which the calcium ion is generally most effective. It seem probable, according to True, that the difficulty lies in the fact that pectates of all of the other bases are more soluble than that of calcium which ordinarily makes up a large portion of the outer layer of the cell wall. In the absence of adequate amounts of calcium in the nutrient solution there is a substitution of other bases. Potassium pectate is readily soluble in water and even magnesium pectate is much more soluble than the corresponding calcium compound. As a result, the permeability of the cell wall is altered and the cell tends to lose its

protoplasmic contents to the nutrient medium. The other essential elements in the solution, or in the soil, are of little use to the plant, therefore, unless the calcium ion is present in sufficient amounts to satisfy the normal needs of the plant in the construction of its cell walls.

The conditions under which crop plants are grown in culture solution work are abnormal. Furthermore, if it were possible to determine what constituted an optimum culture solution for crop plants when grown under such conditions this information would have little value in its application to the soil. This is for the reason that the soil tends to exercise precipitation and adsorption effects which immediately alter the ratios in which the ions are present in the solution. There is the further complication in that the soil solution, being in immediate contact with the soil, tends to be renewed from the soil as the nutrient elements are removed by the growing crop. An interesting comparison of the concentration of nutrient solutions essential to optimum growth of crop plants in the soil and in solution cultures is given by McCall.

EFFECT OF FERTILIZER SALTS ON THE SOIL SOLUTION

The good or bad effects of applications of fertilizers, lime or limestone and manures, to be correctly interpreted, must take these various relationships into consideration. Sulphate of ammonia leaves an acid residue in the soil as compared to the alkaline residue left by nitrate of soda. Acid phosphate not only supplies soluble phosphorus, but precipitates toxic aluminium from acid soils. Limestone supplies the element calcium, but also has an important function in controlling the soil reaction. Heavy applications of manure and soluble fertilizers have an appreciable effect on the total concentration of salts in the soil solution A large amount of investigational work in soils in recent years has been directed toward determining the concentration and reaction of the soil solution, its rate of renewal from the soil

matrix and the influence upon it of applications of manure and the various fertilizer materials.

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CHAPTER XI

DRAINAGE

One of the most important problems in soil management is that of controlling the water supply at as nearly the optimum as possible for the crops it is desired to grow. In humid regions this usually means the following of such practices as will economize on water during, or in preparation for, periods of drouth and will prevent the undue retention of gravitational water by the soil, following periods of heavy rainfall. The conservation of water is ordinarily accomplished by certain tillage operations and by those practices which influence the content of organic matter in the soil. The removal of the excess water is a problem of drainage. It happens that artificial drainage is also indirectly a conservation measure in that by enlarging the foraging area of plant roots it makes it possible for them to use the water which is stored at greater depths in the soil.

THE ROOT SYSTEMS OF CROP PLANTS

Weaver and his co-workers have shown that, under favorable conditions for growth, and in the absence of a water table in the subsoil, the roots of ordinary crop plants penetrated the soil to a depth of from 5 to 8 feet in certain areas in Nebraska, Kansas and Colorado where these investigations of root systems were made. The following table selected from their work is illustrative:

TABLE XXIV

ROOT DEVELOPMENT OF CROP PLANTS (WEAVER)

Crop Variety	Growth Record of Tops		Growth Record of Roots	
	Age, Days	Height, Feet	Depth, Feet	Spread, Feet
Oats—Swedish Select	63	3 0	6 8	1 3
Wheat—Marquis	93	2 7	6 7	1 3
Barley—Manchuria	84	2 3	6 3	1 3
Corn—Silver Mine	116	8 5	8 2	4 0
Potatoes—Early Ohio	94	2 3	4 7	2 1

THE AVAILABLE WATER IN DRAINED SOILS

Assuming that the water table is under sufficient control in humid regions to prevent its rising higher than 3 feet below the surface of the soil, except for short periods after heavy rains, and that this depth therefore represents the space in which crop roots can grow without danger of injury from excess water, it is then possible to estimate the amount of water which is available for crop use under any given soil and climatic environment. Some investigations by Conrey are of interest in this connection. In these studies the soil columns were in contact with a water table at a depth of 6 feet and percolation had been allowed to continue for a period of two months after the soil had been saturated with water. At the end of this time moisture determinations were made on the upper 3 feet of soil. The wilting coefficients for these soils were then estimated. Subtracting these two sets of figures for each soil gives the amount of water which should be available for crop use in the upper 3 feet of these soils when the soil water has come to equilibrium with gravity, after being saturated by rain and under conditions in which the water table is maintained at a depth of 6 feet. If the entire capacity of the soil to hold

water was satisfied when the crop was planted and precautions were taken to maintain a surface mulch until protection was afforded by a rapidly growing crop, the losses of water by surface evaporation need not be excessive. Furthermore, any such losses should be more than compensated for, ordinarily, by the rainfall.

TABLE XXV

AVAILABLE WATER IN UPPER THREE FEET OF SOIL AT POINT OF EQUILIBRIUM WITH GRAVITY AFTER SATURATION

Water Table at Depth of Six Feet

	Percentages of Dry Weight of Soil		
	Dunkirk, Fine Sand	Wooster, Silt Loam	Brookston, Clay
Water-retaining capacity	6.5	30.2	30.5
Wilting coefficient	3.5	7.7	17.5
Available water by difference	3.0	22.5	12.8
Available water in acre inches	1.6	10.5	5.2

Usually, the water table continues to recede during the summer months so that by the time root development to a depth of 3 feet has taken place the water table may perhaps be even more than 6 feet below the surface. As the roots continue to grow downward, additional water becomes available, but the roots are in constant danger of a rise of the water table to the level of the tile, which is usually placed at a depth not to exceed 3 feet below the surface. The water below the depth to which roots extend is not thought to be of any considerable importance, since the rate of movement of water through a subsoil which has been robbed of its water by roots is very slow, particularly when some distance removed from the water table.

RATE OF REMOVAL OF WATER BY DRAINAGE

Too rapid removal of gravitational water from the soil is objectionable for the reason that it tends to carry away with it the soluble nutrients essential for plant growth. On the other hand, it is apparent that the gravitational water cannot be retained in the soil for any considerable length of time without injury to crops from the accumulation of respiratory carbon dioxide and the formation of toxic reduction compounds resulting from anaerobic bacterial action. There is also danger of loss of nitrate nitrogen by denitrification. If the topography of the land is rolling, the rapid absorption of the rainfall by the surface soil is desirable as a means of preventing undue erosion. Ideal drainage will provide for the rapid absorption of the water by the surface soil and its somewhat gradual removal through the tile. An excellent review of the considerations involved in planning effective systems of artificial drainage is given by Elliott.

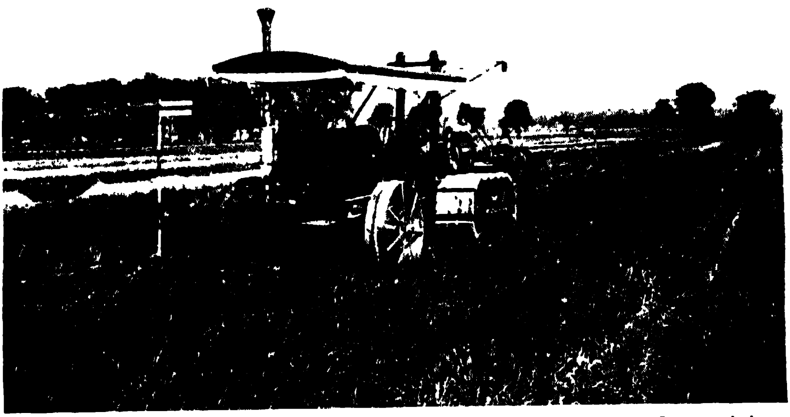

FIG. 12.—"As a general rule soils located in humid climates and containing considerable percentages of silt and clay, particularly if the land is fairly level, have their productive power for ordinary farm crops improved by some system of artificial drainage."

SOME LIMITATIONS TO ARTIFICIAL DRAINAGE

Soils differ to such an extent in the size and arrangement of their constituent particles in both the surface and subsurface zones; the topographic features of the land varies so much from place to place; the climatic conditions are so variable; and the root systems of crop plants are so different in their habits of growth and in their requirements, that it is somewhat difficult to consider tile drainage except as it refers to some particular soil, topography, climate and crop. Some soils lose their gravitational water readily without artificial drainage. Under some climatic conditions the amount and distribution of rainfall may be such that the drainage problem is not serious. Some crops are better adapted for growth on wet soils than are others.

As a general rule, however, soils located in humid climates and containing considerable percentages of silt and clay, particularly if the land is fairly level, have their productive power for ordinary farm crops improved by some system of artificial drainage. The frequency with which the lines of tile can be placed to advantage in such soils is finally limited by the market value of the crops to be grown on the land. In any case a point is finally reached at which it becomes desirable to consider changing the crops to fit the soil and the climate rather than to attempt draining sufficiently to satisfy the needs of some crop which is too exacting in its drainage requirements. This is at times the deciding factor between alfalfa and alsike clover. At other times it may be better to leave the land in permanent pasture rather than to attempt to drain it for the production of ordinary field crops.

SOME EFFECTS OF ARTIFICIAL DRAINAGE OF WET SOILS

King comments on the effect of artificial drainage on the temperature of the soil and records some comparative temperatures on some drained and undrained soils lying adjacent to each other in Wisconsin:

TABLE XXVI

COMPARISON OF TEMPERATURES OF DRAINED AND UNDRAINED SOILS

Degrees Fahrenheit (King)

Date	Time of Day	Air	Drained Soil	Undrained Soil
April 24.	1 P.M.	60.5	66.5	54.00
April 25.	3 P.M.	64.0	70.0	58.00
April 26	2 P.M.	45.0	50.0	41.00
April 27 .	2 P.M.	53.0	55.0	50.75
April 28	8 P.M.	15.0	47.0	44.50

Conner has shown that the amount of limestone required on acid soils is reduced by tile drainage. In a comparison of the lime-requirements of some drained and undrained experimental fields in Indiana he found the following lime-requirements as measured by the potassium nitrate method of extracting the soil:

TABLE XXVII

EFFECT OF DRAINAGE ON "LIME-REQUIREMENT" OF SOILS—CONNER

Pounds Limestone Required per Two Million Pounds of Soil

Field Location	Drained	Undrained
Westport	860	1280
North Vernon	1880	2840
Worthington	740	1600

EFFECT OF DRAINAGE ON CROP YIELDS

An interesting record of crop yields on adjacent drained and undrained sections of plots is found in the data available from the experimental farm on the Clermont silt loam soil in southwestern Ohio. This soil type also covers an extensive area of level land in southern Indiana and Illinois. The soil is usually farmed by plowing it in long parallel

lands having finishing furrows between them to provide for surface drainage. In the comparative tests the same method of surface drainage happens to be in operation since, as is usual in experimental work, the plots are ridged somewhat in order to prevent the soil from being moved from one plot to another. The plots are 21 feet wide, the lines of tile being placed lengthwise of the plots in every second division space. The resulting yields of crops on plots which have been dressed with phosphated manure and limestone are given below:

TABLE XXVIII

EFFECT OF TILE DRAINAGE ON CROP YIELDS (CLERMONT SILT LOAM)

Crops Grown in Rotation	Yields on Unfertilized Land				Increase from Manure and Limestone			
	Undrained Land		Drained Land		Undrained Land		Drained Land	
	Grain, Bu	Stalks, Cwt	Grain, Bu	Stalks, Cwt	Grain, Bu	Stalks, Cwt	Grain, Bu	Stalks, Cwt
Corn	36.2	17.0	49.8	26.8	13.7	1.4	32.0	13.4
Soybeans	16.2	30.0	13.5	23.5	5.6	11.8	5.9	10.8
Wheat	20.8	22.7	24.2	23.3	10.6	10.1	17.5	16.9
Clover	. . .	32.4		28.9		15.5		18.9

The data indicate that the soil lacked uniformity, since the yield on the undrained soil was at times greater than that on the drained soil on the unfertilized plots. Where phosphated manure and limestone are applied there is no question as to the effectiveness of the drainage in increasing the yields. The data are suggestive and indicate something of the extent to which it might seem advisable to make expenditures in tile drainage in preparation for the growing of ordinary field crops.

DRAINAGE WITH IRRIGATION

The ideal arrangement in the soil would be one in which the water table was kept under control throughout the season by drainage and by subsurface irrigation. This is possible in areas located along bodies of fresh water into which the excess water can be pumped and from which it may be returned as needed. The large areas of swamp land lying around the Great Lakes will probably be utilized in this manner when economic conditions warrant. The overhead sprinkling system is also an exceptionally efficient method of control of the water supply in connection with the growth of vegetables. Here, again, it is necessary in humid climates to have the soil well underdrained, since irrigation may be followed by a heavy rain and injury may result from a too prolonged period of excessive water supply.

It is interesting to note in this connection that it is at times found necessary in irrigated districts to provide underdrainage through which an excess of water may be withdrawn as a means of preventing the accumulation of alkali at the surface of the soil.

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CHAPTER XII

TILLAGE

THE operations involved in tillage include those of plowing the soil, pulverizing and compacting it in preparation for seeding and, in the case of intertilled crops, its subsequent cultivation. All of these mechanical processes must be considered in relation to the size and arrangement of the soil particles, the climatic environment of the soil and the crops to be grown. Under certain conditions the topographic features of the land become of paramount importance.

PLOWING

The literature on the subject of plowing is voluminous. Together with other phases of tillage, plowing is discussed at some length in a very interesting and instructive treatise on "Horse Hoeing Husbandry" written by Jethro Tull in 1733. Tull's conception of the purpose of plowing and cultivation was in part erroneous, but his book served to call attention to the importance of these operations in determining the productive capacity of the soil. The implements of tillage have been very materially improved since Tull's day and the work is now much more efficiently done. Considerable attention has been given to fitting the plow to the soil on which it is to be used. The depth and time of plowing have also received consideration.

FITTING THE PLOW TO THE SOIL

King writes that if a soil has gotten out of tilth or has become cloddy, there is a shape of moldboard, a content of

soil water and a depth of furrow slice which will help to restore the tilth most quickly. If, for example, the soil is of a sandy nature and is somewhat excessively open and porous it should be plowed with a steep moldboard, somewhat wet and fairly deep. If the soil has a considerable percentage of silt and is not in good tilth it should be plowed with a moldboard having only a moderate slope and when the soil is somewhat dry. Wet clay should be plowed with a fairly flat moldboard and rather shallow. When the soil is very dry it will be better pulverized with the use of a steep moldboard and deep plowing.

In manufacturing moldboards to suit different soils and soil conditions four distinct types have been developed. The sod moldboard is long and slopes upward gently with considerable twist which prevents the furrow slice from falling back into the furrow and tends to break the sod apart. The stubble moldboard is quite steep and short and pulverizes the furrow slice as it turns it over. The breaker rod and disk types of plows are found satisfactory in soils which will not scour the moldboard. The last named is also useful in soils which must be plowed while very dry. The use of the wrong type of plow may make it almost impossible to prepare a good seed-bed. A soil in a low state of productivity can often be made to produce a fairly satisfactory crop, under suitable climatic conditions, if it is properly plowed and the seed-bed is given adequate preparation.

DEPTH OF PLOWING

It is considered good practice to vary the depth of plowing according to the nature of the soil and the crop to be grown. Soil is usually plowed to a greater depth for corn than for oats or wheat. Especially deep plowing has been recommended for such crops as potatoes and alfalfa. The depth of plowing is determined in many cases, however, by the general level of the productivity of the soil and the

amount of organic residues, fertilizer and other materials available for incorporation with it. There is probably little to be gained by plowing deep if in so doing the available mineral nutrients and nitrogen of the surface soil are simply diluted with unproductive subsoil. The plowed surface usually contains the greater portion of the feeding roots of plants particularly during the early period of their growth. Subsoil mixed with this may not only dilute the available nutrients, but may have a toxic effect on the young seedlings.

The experiments which have been conducted on the depth of plowing are unsatisfactory in that the related program of soil management usually has been inadequate when applied to such an extended depth as is broken up with the deep tillage implements. It is generally recognized that subsoil is " raw " and if it is to be made a part of the surface soil this should preferably be done very gradually. For this reason deepening the soil has usually been attempted by using either a subsoiler, which follows after the ordinary moldboard plow and breaks up the bottom of the furrow, or by the use of a double disk device which turns two furrows. One of the disks is behind and below the other and has little tendency to throw the subsoil on the surface although some mixing occurs.

Williams reports data on crop yields, following these different methods of plowing, covering a period of twelve years at the Ohio Station, from a rotation of corn, oats, wheat and clover. The ordinary plowing was of a depth of $7\frac{1}{2}$ inches while the double disk plow turned the furrow to a depth of 15 inches by the method indicated above.

TABLE XXIX

Depth of Plowing Experiment on Wooster Silt Loam Soil

Twelve-Year Average Yields per Acre

Crop	Ordinary, 7½ Inches	Double Disk, 15 Inches	Ordinary, with Subsoiling
Corn, bu	61.1	59.1	61.3
Oats, bu	19.0	49.2	49.0
Wheat, bu	31.5	31.4	31.6
Clover, cwt	53.0	50.6	52.0

Morrow and Gardner studied the effect of different depths of plowing with the ordinary moldboard plow on the yield of corn in Illinois, with average yields as given below:

TABLE XXX

Yield of Corn as Influenced by Depth of Plowing

Illinois Brown Silt Loam Soil (Six-Year Averages)

Depth of Plowing	Bushels per Acre
Disked Surface	56.1
2 inches	59.9
4 inches	69.1
6 inches	69.3
8 inches	71.1

Other examples are given in the literature, as reviewed by Sewell, which indicates that little if anything has been shown to have been gained by plowing to a depth exceeding 6 or 7 inches.

DATE OF PLOWING

A matter of considerable importance in sections in which the winters are cold and the summer seasons are relatively short is that of the time to plow for best results with spring and summer crops. Ordinarily, the distribution of the

labor on the farm makes fall plowing desirable. Other than this, however, it has not been shown that anything is gained by fall plowing in the Central States which cannot be equally well accomplished by early spring plowing, unless it be that of the destruction of the larvæ of insects. The undesirable features of fall plowing are to be found in the failure to take advantage of an opportunity to grow a cover crop and the losses which may occur through leaching and erosion. The farther north the location the less these objections apply. It is apparent that if for any reason spring plowing is delayed, the losses by transpiration and evaporation may be such as to prevent the storage of sufficient amounts of water in the soil to satisfy the needs of the summer crop in seasons of scanty rainfall.

King comments on the difference in the moisture content of two adjacent strips of sod land one of which was plowed on April 29th and the other was left unplowed.[1] Samples of soil were selected from the two areas on May 6th, only 7 days later, at which time it was found that the plowed soil contained 1.75 inches more water in the first 4 feet of depth than the unplowed. There would undoubtedly be a considerable difference between the water content of soils plowed in March and May, particularly if the field was covered with a rank growth of some green manuring crop such as rye or sweet clover. The necessity of plowing as far as possible in advance of planting the crop is found to be especially essential in semi-arid sections where it is necessary to have the soil in condition to absorb the rainfall and to prevent loss of water through transpiration by weeds.

When plowed soil is subjected to the action of freezing temperatures it tends subsequently to be easily prepared for the crop. If the plowing is done in the fall and the winter weather is mild, the freezing and thawing may be entirely overcome by the action of rains which tend to cause the soil to "run together" at times when it is thawed.

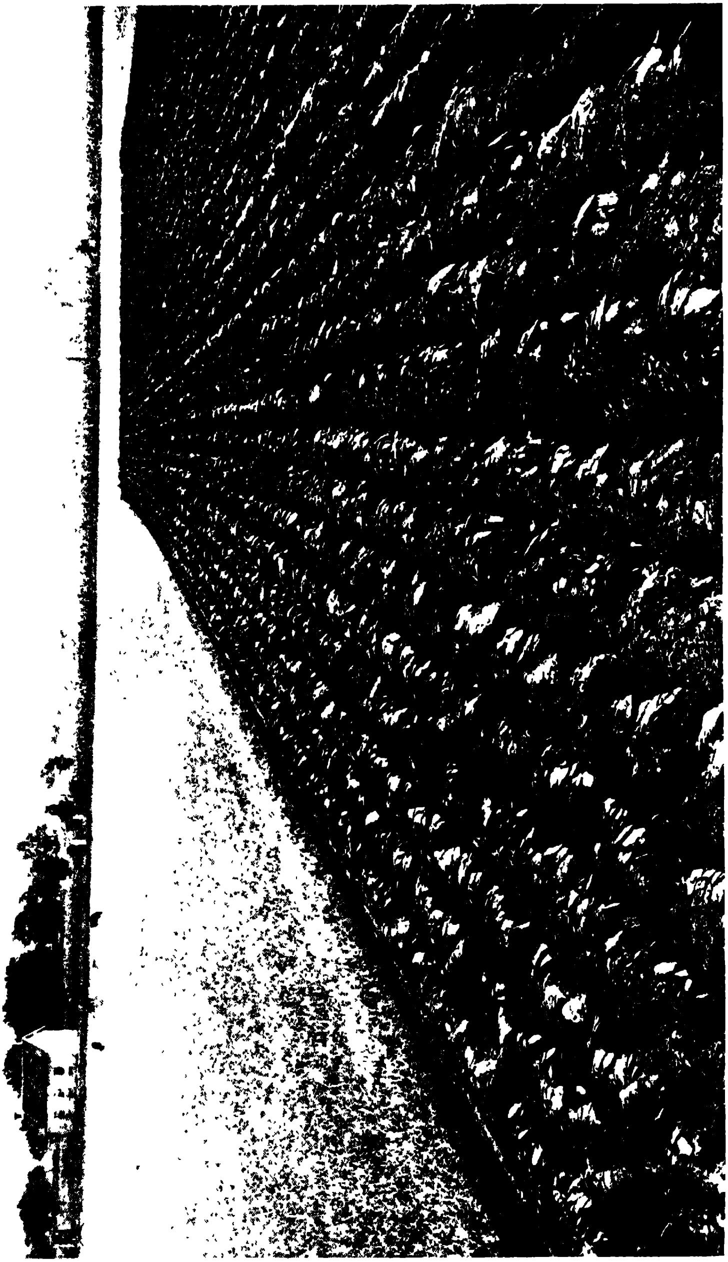

FIG. 13.—"If a soil has gotten out of tilth or has become cloddy there is a shape of mold board, a content of soil water and a depth of furrow slice which will help to restore the tilth most quickly." Good plowing of clay loam soil. (Courtesy, Oliver Chilled Plow Company.)

It is for this reason that early spring plowing is sometimes better than fall plowing if the work can be done sufficiently early to be assured of several freezing nights. Stiff clay soils, or those which are somewhat wet or difficult to manage, will usually become quite friable under such conditions. Extremely cold winters or hot dry summers will usually be found to have a marked effect in improving the tilth of the soil in the following season, probably by reason of the dehydrating effect of these processes on the colloidal material in the soil.

PREPARATION OF THE SEED-BED

If the plowing has been well done the subsequent preparation of the seed-bed is usually accomplished without difficulty. This is particularly true where the soil has enjoyed some years of good management in which attention has been given to drainage, the use of lime, and the incorporation of organic matter with the soil, as well as to good plowing. If this has not been the case and if the weather happens to be unfavorable, the problem of seed-bed preparation is by no means simple. Much depends upon the skill and experience of the farmer in dealing with similar soils and conditions.

In preparing the plowed soil for seed or plants it is desirable to make the surface soil fine and free of clods while the sub-surface soil must be compact and also free of clods. The first is essential in order to get the seed planted and the second to provide for a continuous flow of capillary water from the subsoil. For this reason the use of an implement which will both compact and pulverize is desirable. The objection to the roller lies in the fact that the clods are often simply pressed into the soil, but not pulverized. Furthermore, the roller leaves the surface smooth and compact and tends to encourage the loss of water by evaporation. The smoothing harrow has its chief value on soils which are in good tilth and as a means of providing a surface mulch and killing early weeds. Various other

implements are in use which are found to be valuable, depending upon the condition of the soil and the needs of the crop. The disk is one of these which is found to be an especially efficient tool in breaking up a soil that has become too compact for planting the crop. The cultipacker is a more modern implement combining some of the desirable features of the smoothing harrow and the roller and also being very effective in pulverizing clods.

CULTIVATION TO CONSERVE WATER

Cultivation previous to seeding the crop or between the rows of an intertilled crop was believed to be essential, from King's experiments, in conserving water. In semiarid regions having a sparse rainfall and a high rate of evaporation, dry farming is practiced, the success of which is assumed to lie in the prevention of evaporation for a long enough period to store up sufficient rain to satisfy the requirements of a crop. In some regions this means growing a crop only every second year, with frequent cultivation of the soil during the intervening summer. In other regions it means plowing the soil some months in advance of planting the crop and practicing clean cultivation to conserve the water in the soil and any additional rain which may fall before the crop is planted. Dry farming practices, as well as the ordinary cultivation operations, are assumed also to increase the rate of nitrification so that the crop is believed to benefit from additional supplies of both water and nitrates.

A good review of the data on the effectiveness of the soil mulch is given by Sewell. Call and Sewell also report data which have been secured from experimental plots at Manhattan and Garden City, Kansas, in which it was shown that continued cultivation throughout the season had not resulted in any appreciable conservation of water or in an accumulation of nitrates. In their study of the problem, plots of ground, set aside for the purpose, were either kept

bare of weeds by being scraped with the hoe or by cultivation to depths of 3 and 6 inches, respectively, in comparison with plots on which the weeds were allowed to grow. Moisture determinations to a depth of 6 feet were made from time to time during the summer. A comparison of the average moisture content, in the autumn and spring, of the entire 6 feet is given in percentage of the dry weight of soil in the following table:

TABLE XXXI

EFFECT OF SURFACE MULCH ON CONSERVATION OF WATER (CALL)

Marshall Silt Loam (Manhattan, Kansas)

Year	Rainfall, Inches, Jan. to Sept	Per Cent Water in Autumn Compared to that in Spring			
		Weeds	3-inch Mulch	6-inch Mulch	Bare Surface
1914	17 93	−7 28	−3 31	−1 86	−0 89
1915	44 97	−1.20	0 70	−0 05	−0 70
1916	29 89	−6 65	−2 39	−1 19	−2 50
1916 (diked)	29 89	−3 65	0 20	2 37	2 88

From this and other data secured at Manhattan and Garden City, the conclusion was drawn that a cultivated soil was no more effective than an uncultivated one in preventing the evaporation of water. In so far as cultivation did aid it was assumed to be by the elimination of weeds and the prevention of surface run-off. It was also found that nitrification was not materially affected by cultivation.

CULTIVATION OF CORN

A number of experiment stations have studied the time, depth, and frequency of cultivation of corn in their effects on yields. Probably the best summary of this type of investigation is that of Cates and Cox in which records are

given of yields produced by ordinary cultivation as compared to those secured under conditions in which the weeds were kept down by scraping with a hoe. As a result of 124 such tests scattered over 28 states it was found that the yields on the uncultivated plots were practically equal on the average to those on the cultivated plots. A wide variety of soils was selected and the climatic conditions were quite different. The following table presents a part of the data from these investigations:

TABLE XXXII

COMPARISON OF CULTIVATION AND SURFACE SCRAPING ON CORN YIELDS

Yield of Uncultivated Plots as Percentage of Yield of Cultivated Plots

State	Number of Tests	Percentage Yields
Ohio	10	96
Indiana	9	105
Illinois	8	94
Iowa	7	102
Missouri	3	103
Kentucky	9	91
South Carolina	12	99
Virginia	9	88
New Hampshire	10	112
Total, all States	121	99
Ten plots most benefited by cultivation		69
Ten plots most injured by cultivation		135

These and other cultivation tests indicate that on the average little is to be gained by cultivating the corn crop which is not accomplished by any scheme which will eliminate weeds as competitors. It is possible, however, that cultivation may result in injury to the corn roots and that the yield obtained is the resultant of benefit and injury from the process. The Kansas results indicate that conservation of water is of little importance. To apply the Kansas data to the corn belt would neglect the differences

in the rainfall-evaporation ratio. Perhaps the corn plant prevents loss of water by surface evaporation through having a well-distributed root system, a need for large amounts of water and a sufficiently large growth to prevent the rapid movement of air through the field, by which evaporation is hastened.

In practice the only logical thing to do is to begin with fairly deep cultivation while the plants are young and before the root systems are extended, and then to continue to reduce the depth with each cultivation. By this means weeds can be eradicated and the corn roots least disturbed. An excessive number of cultivations beyond that required to control weeds has not been shown to be of any value to the crop. In looking over the data of Cates and Cox, a few examples are found in which it is shown that cultivation increased the yield by more than 50 per cent, but in other cases its effect was to decrease the yield by an equal amount. It is possible that there may be some correlation between the climate, the soil and the crop yield as related to cultivation, but as yet this is not apparent.

TILLAGE AND SOD CULTURE IN ORCHARDS

The relative merits of tillage and sod culture in the apple orchard have been discussed at considerable length, notably by Hedrick, who was of the opinion, from some experimental work along this line conducted under his supervision, that tillage was much more desirable than the sod culture system. From these and other investigations it is now believed that the tillage method is to be desired, when the land is level, in that in the process nitrates are accumulated and the soil continues to yield up considerable quantities of available nitrogen for the trees for some years. It is quite common in this system to grow cover crops during the latter part of the season, to be plowed under the following spring. It is evident that the good effects of the clean culture method might be more than overcome by erosion if

the land was rolling or hilly. It has been found good practice in such sections to follow the clean culture and cover crop system for a few years, until the trees are well established, and then to stop the cultivation and make use of the cover crops to provide a mulch under the trees. An excellent review of the investigational work on cultural methods in orchards is given by Gourley.

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CHAPTER XIII

ORGANIC MATTER

PLANT residues are a very essential part of most productive soils. They serve as a source of food for energy and growth of many desirable soil organisms. In the decay of these residues the elements contained in them are liberated for the use of crops. In addition the carbonic and other acids produced, when dissolved in the soil water, increase its solvent action on the hitherto undissolved soil minerals. Plant residues also function as agents to improve the tilth of soils and in increasing their water-holding capacity. In general it may be said that soils are in best condition to produce satisfactory yields of crops when they are well supplied with the refuse of previous crops, particularly that of recent origin.

THE SOIL "HUMUS"

The early soils literature is filled with references to "humus," a name which has long been used to designate collectively the plant residues which remain after the most easily oxidizable portions have been decomposed. Investigation has shown that, if a soil is first digested with dilute hydrochloric acid, the humus can then be extracted from it by treatment with dilute ammonia water. The effect of the acid is to separate from the humus the basic elements with which it forms insoluble "humates" with the result that the "humic acids" are released. These give a brown to black color to the solution of ammonium hydroxide.

Humus has such an indefinite meaning and the method

of determining the quantity of it in the soil is so empirical that the word is no longer in good standing in soil terminology. While it is generally believed that these decay-resistant organic residues have a value in improving the physical qualities of the soil, the more recent point of view seems to be that the greatest need of the soil is for fresh organic residues, particularly those of leguminous origin, which are undergoing fairly rapid decomposition. It is apparent, therefore, that the determination of the total amount of organic matter in the soil is of little value unless something is known of the cropping system being employed and the probable source and age of the organic residues present.

ESTIMATING THE ORGANIC MATTER IN SOILS

The estimation of the quantity of organic matter in a soil must be based on some one element contained in it. Of these, carbon and nitrogen are the only ones which are not present in inorganic combinations as well. Even with carbon there is an exception in the carbonates, but the two forms can be separated either by the use of dilute acids or by controlling the temperature in combustion methods. The carbon dioxide resulting from the oxidation of the organic matter is usually absorbed and weighed in bulbs containing potassium hydroxide. The ratio of carbon to organic matter varies considerably, but it is ordinarily estimated that approximately one-half of the latter is carbon. The ratio of nitrogen to carbon is usually about 1 to 12. A study of this ratio in corn-belt soils is given by Stewart who reports it to be 1 to 12.1 on 68 gray and brown silt loams, 1 to 11.7 on 25 black clay loams and 1 to 11.8 on 5 peat soils. A soil containing 3500 pounds of nitrogen per acre to plow depth would contain approximately 40,000 pounds of carbon and twice this amount of organic matter.

SOLVENT ACTION OF ACIDS FROM ORGANIC MATTER

The several functions of organic matter in soils have not been studied separately to any considerable extent. It is generally recognized that dark colored soils have, as a rule, a somewhat greater productive capacity than the lighter colored soils of the same locality. It is not always easy in these and similar cases to distinguish between cause and effect. In a previous chapter mention was made of the fact that, if all of the nitrous acid produced in the nitrification of sufficient nitrogen to satisfy the requirements of a 100-bushel crop of corn acted on phosphate rock, seven times as much phosphorus would be made available as would be required by the crop. Certainly a part of the value of organic matter must lie in the solvent effect of the acids produced in its decay on the mineral compounds in the soil. Cameron and Bell found that the solubility of the potassium of orthoclase was increased from 1.7 to 2.5 p.p.m. by saturating the water with carbon dioxide. It seems questionable, however, whether anything is gained in having an amount of carbon dioxide in the soil in excess of that given off in the respiration of plant roots since it tends to become toxic in its effects when present in excess. This was shown in the necessity for aerating solution cultures of plants and in the fact that wilting occurred when carbon dioxide was aspirated through the solution.

ORGANIC MATTER IN RELATION TO NITROGEN FIXATION

The function of carbohydrate materials in nitrogen fixation processes has been well established. Following the methods of Ashby, the carbohydrates employed in studies of non-symbiotic fixation have usually been mannit, lactose or sucrose. In such experiments, carried on under optimum conditions in laboratory control, fixation at a rate of 200 pounds or more per two million pounds of soil, in three weeks' time, has been repeatedly observed. The

assumption is that the starch, cellulose and similar carbohydrate materials, in the fresh residues of plants, satisfy the energy requirements of these organisms in the soil. The nitrogen accumulation in Geescroft field at Rothamsted, previously referred to, amounted to approximately 40 pounds per acre per year. Probably the plant accumulations resulting from allowing the land to "run wild," furnished the necessary carbohydrate materials in abundance.

EFFECT OF ORGANIC MATTER ON PHYSICAL PROPERTIES OF SOILS

The tilth of the soil and its water-holding capacity are very much improved by increasing the amount of organic matter in the soil. A comparison of the garden, which is usually very heavily manured every year, with the nearby fields, on which the quantity of manure applied is too small to be of any particular significance as a direct source of organic matter, makes this apparent. The experience of farmers in this connection is sufficient justification for the belief in the necessity of a system of farming which makes adequate provision for the addition of organic matter to the soil as a means of improving its working qualities.

Of greatest interest and importance in this connection are the means by which the quantity of organic material may be increased without sacrificing crops or parts of crops which have a sale or feeding value. Ordinarily a suitable crop rotation such as corn, wheat and clover, with a return to the soil of the manure produced from feeding part or all of the crops, is made to satisfy the requirements. The value of manure is assumed to be not only that of returning the necessary mineral elements and nitrogen to the soil, but also one of adding to the supply of organic matter. This is one reason why manure is preferred in many cases to the inorganic fertilizers. Because of the enormous number of bacteria contained in it, manure may at times have an added value as an inoculant.

FIG. 14.—"Soils are in best condition to produce satisfactory yields of crops when they are well supplied with the refuse of previous crops, particularly that of recent origin."

RELATIVE VALUES OF MANURE AND FERTILIZER

Of recent years the question of the substitution, in part or in whole, of fertilizers for manure has brought this problem of organic matter maintenance and increase to the foreground. It is interesting to compare the yields of crops produced by manure and fertilizers and to study the

content of organic matter in the soil following the two different methods of supplying the mineral needs of plants. Thorne has commented on the fact that fertilizers are more efficient than the same amount of mineral elements and nitrogen supplied in the form of manure, and questions the value of the organic matter in the manure beyond its capacity to yield up the necessary elements to crops. A somewhat better conception of this is probably to be found in the assumption that the organic matter in the soil is increased somewhat in proportion to the yield of the crops produced, through the residues left behind in their roots and stubble, and that, if fertilizers grow larger crops, the organic residues may be enough more than those produced from the use of manure to compensate for the organic matter supplied in the manure. The following table is of interest in this connection as bearing on the relative yields produced by manure and fertilizers:

TABLE XXXIII

COMPARISON OF YIELDS PRODUCED BY MANURE AND FERTILIZERS

25-Year Average Yields (Wooster Silt Loam Soil)

Treatment* Quantities Supp	Fertilizers, 1060 Lbs	Manure, 8 Tons	Manure, 16 Tons
Nitrogen, lbs	76	72	144
Phosphorus, lbs	20	21	48
Potassium, lbs	108	56	112
Yield per acre.			
Corn, bu	46.8	42.9	52.5
Oats, bu	51.2	39.5	46.6
Wheat, bu.	28.1	19.6	24.1
Clover, cwt	29.8	26.8	36.9
Timothy, cwt	34.5	34.2	41.4

* Fertilizers divided among corn, oats and wheat. Manure divided between corn and wheat.

RELATION BETWEEN CROP YIELDS AND CONTENT OF ORGANIC MATTER IN SOILS

The relationship between crop yields and the amount of organic matter which accumulates in the soil in the crop residues is shown in the work of Bear and Salter, who examined the soils of a series of fertilizer plots after fifteen years of cropping in which all the crops had been removed from the soil as produced. The only possible source of the accumulated organic matter was the residues left behind in their roots and stubble. Where manure was applied some organic matter was added and the comparison is interesting for that reason.

TABLE XXXIV

Effect of Fertilizers on Accumulation of Organic Matter Dekalb Silt Loam Soil (During Fifteen-Year Period)

All Crops Harvested and Removed

Treatment of Soil	Fertilizers Applied in 15 Years Tons per Acre	Total Produce in 15 Years Pounds per Acre	Organic Matter in Soil at End Pounds per Acre
No fertilizer	None	10,960	12,800
Complete fertilizer	5	117,910	60,800
Manure	190	139,670	73,600
Complete fertilizer and lime	7½*	120,605	49,000
Manure and lime	212½*	152,100	65,000

* 2½ tons of burned lime

The manure and fertilizers were both added in liberal amounts. The manure carried considerably more of nitrogen and of the mineral elements than the fertilizers, supplying, for example, 2000 pounds of nitrogen per acre during the fifteen-year period as compared with 675 pounds of nitrogen in the complete fertilizer. The interesting phase of the comparison lies in the accumulation of organic matter in

the soil, resulting from the application of purely inorganic fertilizers made of nitrate of soda, acid phosphate and sulphate of potash. Supplementing the fertilizers and manure with lime increased the total produce, but decreased the accumulation of organic matter. The addition of lime stimulated bacterial action to such an extent that the rate of decomposition came to equilibrium with the organic matter accumulating capacities of the roots and stubble of the crops at a somewhat lower content in the soil. A variety of crops were grown in the test but these would probably correspond fairly well in their effect to that produced by such a rotation as corn, wheat and clover.

The color and physical characteristics of the soils of the plots receiving liberal applications of manure and fertilizers, and for that reason growing much larger crops and accumulating more root and stubble residues, were markedly different from those of the unfertilized plots at the end of the fifteen-year period. It would appear that soil organic matter is largely a by-product of those farming practices which result in large crop yields. The residual effect of fertilizers and manure may be in part due to the accumulated residues left behind by the larger crops grown as well as to any unused mineral elements or nitrogen which may have been supplied.

EFFECT OF GREEN MANURES ON CROP YIELDS

Where green manuring crops, heavy root and stubble growth of hay crops or residues of any recently grown crop are plowed under it would seem logical to believe that the mineral elements and nitrogen contained in these would soon become usable for the succeeding crop. Pieters has prepared an extended review of the literature on the effect of green manuring crops or crop residues on the yields of the crops following. Among the data given are some recorded by Saunders and Shutt of Canada which are of especial interest in this connection. The clover was grown

as a catch crop and plowed under the subsequent spring and the plots were planted to oats, which was followed by corn and potatoes. The yields were as follows:

TABLE XXXV

EFFECT OF CLOVER AS A GREEN MANURING CROP (Canada)

Previous Crop	Oats, Bushels	Fodder Corn, Tons	Potatoes, Bushels
Wheat—no clover	63 5	16 4	353
Wheat-clover	72 9	22 8	396
Barley—no clover	61 1	17 3	346
Barley—clover	70 5	23 6	386
Oats—no clover	58 8	15 0	358
Oats—clover	70 5	20 4	392

In each case the yields were very materially increased by the use of clover, and the good effects carried over to the corn and the potatoes following. A part of this may be accounted for by the increased amount of nitrogen which is assumed to have been fixed by the clover. Lyon and Bizzell's work would indicate that clover may be more valuable than a non-legume as a catch crop, not only because of the nitrogen which the crop has accumulated from the air, but also because the clover residues are more readily nitrified, probably because of a more favorable nitrogen-carbon ratio. Pieters concludes that the evidence on the value of non-leguminous green-manure crops is inadequate, but that the good effect of legumes when used in this capacity has been well established.

SOME IMPORTANT CATCH CROPS

The economy of growing a crop purely for green manuring purposes seems doubtful if this means the loss of the use of the soil for a crop season. Catch crops can be used to advantage between other crops and under good man-

agement may satisfy the organic matter requirements of the soil. They serve to conserve nitrogen and to prevent erosion as well as to store up a supply of readily available mineral nutrients for the next crop. The choice in catch crops is somewhat limited in the Northern States but a great variety are available for the Southern States where they are most seriously needed. South of the Mason and Dixon line, crimson clover is a valuable winter catch crop. North of this line, rye and vetch are in most common use. Of recent years sweet clover has come into prominence as a catch crop to be sown with small grains for plowing under the following spring in preparation for corn or some other cultivated crop. Limestone and inoculation are the two outstanding requirements of this crop.

Whiting and Richmond give some data on the height, weight and nitrogen content of sweet clover, at dates when it was plowed under for corn on experimental fields in Illinois, which are significant:

TABLE XXXVI

WEIGHTS AND NITROGEN CONTENT OF SPRING GROWTH OF SWEET CLOVER IN ILLINOIS

Calculated on Acre Basis (Whiting)

Field	Date of Sampling	Height, Inches	Green Weight, Tons	Nitrogen, Pounds
Urbana	May 2	13	5.8	98
Minonk	April 26	12	9.1	161
Joliet	April 29	9	7.9	133
Toledo	May 9	26	12.8	196
Newton	May 10	22	12.6	188
Raleigh	May 1	19	12.7	129
Enfield	May 1	18	8.7	124

By plowing under this fresh leguminous material it was found that an abundance of nitrate nitrogen was present

in the soil during the growth of the following corn crops. Undoubtedly considerable amounts of phosphorus, potassium and other essential elements were yielded up by the sweet clover in time for the corn crop.

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CHAPTER XIV

CROP ROTATION

The farther removed the soil is from the virgin state, the more necessary it becomes to consider crop rotation as a means of economizing in the resources of the soil, and as an aid to the control of diseases, insects and weeds affecting the crops grown. Economy in the use and distribution of labor also forces the adoption of the rotation principle, particularly as the farms become smaller and the diversity of crops increases. A consideration of the relationship of crop rotation to successful field management is given by Parker in which the great variety of interrelated reasons for the practice are made apparent.

CONTINUOUS WHEAT AT ROTHAMSTED

Because of the length of time during which the tests have been under way, the continuous wheat experiment on the Broadbalk Field at Rothamsted is of especial interest. The soil is a cherty clay loam fairly liberally supplied with the mineral elements and containing an abundance of carbonate of lime. Wheat was sown on these plots in 1844 and has been grown continuously every year since. The climatic conditions are favorable for high yields. By the use of liberal amounts of manure and fertilizers, the yields have been maintained at a rather exceptionally high level during the entire period. The following table shows the average yields on certain of these plots by ten-year periods:

TABLE XXXVII

CONTINUOUS WHEAT IN BROADBALK FIELD (ROTHAMSTED)

Average Yields in Bushels per Acre

Periods	Unmanured	Manured *	Best Fertilizer †
1844–51	17 2	28 0	. .
1852 61	15 9	34 2	36 1
1862–71	14 5	37 5	40 5
1872–81	10 4	28 7	31 2
1882–91	12 6	38 2	38 4
1892 01	12 3	39 2	38 5
1902 11	10 9	35 1	37 2

* 14 tons annually

† 1150 pounds annually of approximately a 13–6–9 fertilizer together with 300 pounds of sodium and magnesium sulphates

Notwithstanding the favorable opportunities enjoyed by the parasites and competitors of the wheat crop, the failure of such a system of cropping to take advantage of the opportunities to maintain a somewhat more favorable mineral balance in the soil such as is assumed to result from a well-selected crop rotation, and the lack of any attempt to supplement the nitrogen resources of the soil by the growth of legumes, the yields have been maintained at what might be considered a remarkably high level on the unmanured plot. On the plots receiving manure and fertilizer, the yields have been exceptionally heavy. No mention is made in the literature of any especial difficulty with plant diseases or insects, but it has been necessary for many years to cultivate the wheat with hoes in order to eradicate troublesome weeds. In 1914 the west half of the plots and in 1915 the east half was fallowed of necessity as an aid in controlling weeds.

The amounts of manure and fertilizers used in these tests were much larger than would be required to produce such yields under more favorable systems of soil management when accompanied by a suitable rotation scheme. In the Agdell Field nearby, on which the Norfolk rotation of

wheat, barley, turnips and clover or beans has been followed since 1884, the average yield of wheat covering the intervening period to 1911 has been 24.3 bushels on the unmanured plot and 38 bushels on the plot receiving mineral manures but no nitrogen. Larger yields are produced with greater economy by following a suitable rotation scheme.

EFFECTS OF ROTATION AND CONTINUOUS CROPPING ON YIELDS

Another interesting test of the capacity of soils to continue to produce crops without the use of supplemental manure or fertilizers is given in the Ohio Experiment Station data from Wooster. A comparison is possible between the yields of corn, oats and wheat when grown continuously and when grown in rotation with clover and timothy. The soil, Wooster silt loam, is not naturally highly productive although it responds exceptionally well to fertilizers and manure. The yields covering the twenty-five-year period from 1894 to 1918 follow:

TABLE XXXVIII

COMPARISON BETWEEN CONTINUOUS CROPPING AND ROTATION
NO FERTILIZERS—ROTATION CORN, OATS, WHEAT, CLOVER, TIMOTHY
25-Year Average Yields—Bushels Per Acre

Years	Corn		Oats		Wheat	
	Continuous	Rotation	Continuous	Rotation	Continuous	Rotation
1894–1898	26.2	31.8	28.1	30.9	10.0	9.2
1899–1903	16.7	30.8	20.4	28.3	8.1	8.5
1904–1908	10.4	31.0	21.9	34.5	6.1	13.6
1909–1913	8.4	20.3	18.1	26.1	5.4	11.3
1913–1918	9.1	24.7	20.4	10.2	8.4	11.3

A variety of explanations for the better yields with rotation may be given. The soils investigator would suggest the effect of the legume in connection with nitrogen

fixation; the more nearly equal distribution of the mineral losses from the soil; the better control of competing weeds and of parasitic soil organisms; the checking of losses by leaching and erosion; the addition of more organic matter by the growth of clover and timothy; and other reasons which will be discussed later.

EFFECTS OF CROPS ON THOSE WHICH FOLLOW

It will be recalled that the "toxicity theory" of soil unproductiveness was based on the assumption that plants excreted substances during growth which were toxic to other plants, particularly those of the same species. Subsequent investigations have shown, apparently, that the only excretory product of plant roots which might be assumed to cause injury to the same or other crops is carbon dioxide. In the absence of cultivation it is possible in heavy or wet soils that reduction products might result from the decomposition of organic matter which might be toxic to plants or to soil organisms. The quantity of toxic inorganic compounds in the soil solution might also be increased by growing plants which had a considerable need for calcium.

Certain field observations have resulted in the belief that crop sequence is an important part of crop rotation and that each crop in some way affects the crop following. This is evidenced by the differences in yields of the same crop when following a variety of other crops grown for the specific purpose of testing this point. A rather remarkable example of such differences in yields is given by Hartwell and Damon in some Rhode Island data on this subject in which a series of plots, producing different crops, were planted, after two years, to the same crop. Subsequently the original crops were grown another two years and a common crop planted over the entire series a second time. The three common crops grown were onions, buckwheat and alsike clover.

TABLE XXXIX

EFFECT OF CROPS ON YIELDS OF THOSE WHICH FOLLOW (HARTWELL)

A Different Crop on Each Plot Two Years—A Common Crop One Year. Yields of Common Crops in Bushels or Hundredweight per Acre

Previous Crop	Onions	Buckwheat	Alsike *
Onions	289	20 8	79
Potatoes	110	22 7	70
Beets	72	20 5	73
Turnips	99	33 8	74
Cabbage	88	20 2	73
Buckwheat	112	13 0	70
Corn	286	5 4	76
Millet	319	4 4	66
Oats	346	15 0	73
Rye	187	21 5	85
Red top	524	9 6	86
Timothy	362	4 4	76
Alsike clover	415	7 3	50
Red clover	249	7 5	53

* Alsike grown two years

The variation in the yield of the following crop is most marked on acid soils such as those on which the Rhode Island tests were conducted. A subsequent bulletin presented data which indicated that the yield of the onion crop, which grows best on limed soils, was largest following the previous crop which least affected the soil reaction, viz.: redtop. It is possible that in other cases the explanation may be found in some other element. The observation of Lyon and Bizzell, previously noted, would indicate that the residues of crops may vary in their effect on the subsequent rate of nitrification.

CROP SEQUENCE IN ROTATION

It is a matter of common knowledge in the Central West that the yield of wheat following oats, tobacco, potatoes or soybeans is usually considerably higher than that following

corn. In the ordinary grain belt rotation it is a matter of considerable importance to determine whether the sequence should be corn, oats, wheat, clover; corn, oats, clover, wheat; or corn, wheat, oats, clover. Factors other than the soil may decide this point unless it is shown that the yields may be considerably better with some other sequence.

The fact that the differences in yield, as related to the

Limed Sweet Clover Unlimed

FIG. 15.—"The importance of the legume crops in general farming rotations is such as to make it desirable to watch carefully any limiting factors which tend to prevent their successful growth." Photograph from Ohio Experiment Station Farm at Wooster

previous crop, are magnified on acid soils would make it appear advisable to arrange the crops in the order of their need for lime, once it had been applied. The question also arises as to whether it is desirable to attempt to fit into the same rotation, crops having such different lime-requirements as, for example, alfalfa and oats. In acid soil sections it is easily possible that one field could best be set aside for alfalfa and devoted almost exclusively to that purpose, with liberal applications of limestone and phosphate, while the remainder of the farm might be devoted to other crops

in rotation which were less sensitive to acid soil conditions and to which less lime need be applied. The popularity of sweet clover as a green manuring crop may possibly wane when the soils become more acid if it is found impracticable to maintain the limestone content at a point sufficiently high to satisfy the requirements of such a crop. On the other hand, it is possible that the value of these crops for soil-improving purposes may justify the use of enough limestone to guarantee their successful growth.

THE LEGUME CROP IN GENERAL FARMING ROTATIONS

The importance of the legume crops in general farming rotations is such that it is essential that careful attention be given to the control of any factors which tend to prevent their successful growth. Of particular interest in Corn Belt rotations is the popular little red clover. As soils become older and somewhat deficient in available mineral elements as well as in carbonate of lime, this crop usually gives way gradually to alsike clover, which may subsequently yield to timothy. The remedy, as a rule, is the more liberal use of phosphatic fertilizers and the application of limestone. Of recent years more difficulty has been experienced with certain insects and diseases which attack red clover but which are not troublesome with alsike or sweet clover. Particular mention should be made of clover anthracnose in this connection. The remedy lies in the lengthening of the rotation or in the substitution of other legumes every other time around the rotation. Similar troubles are experienced with other legume crops. It seems desirable to add that the losses from diseases and insects will be much less if attention is given to maintaining an adequate supply of mineral elements in the soil and a favorable reaction of the soil solution. Something can be done in choosing the legume to fit the conditions. The substitution of non-legumes is not feasible except in more intensive systems of farming in which the selling price of

the crop is sufficiently high to justify the purchase of the necessary fertilizer nitrogen.

INSUFFICIENCY OF CROP ROTATION ALONE

Hopkins has called attention to the fact that crop rotation cannot be considered as adding anything to the soil (excepting nitrogen secured by the nodule organisms of clover and even the gain from this source is questioned if the crop is harvested and removed) but that it very definitely increases the rate at which the elements are removed from the soil by reason of the larger crops grown. Coupled with a system of livestock farming in which these crops are returned in large part as manure, or with adequate provision for the return of the essential mineral elements and limestone in commercial forms, rotation helps to improve the productive capacity of the soil as the years advance. Failure to take into consideration the requirements of these large yields soon results in the exhaustion of the available mineral nutrients and in a reduction in yields even on the best of soils and with the most desirable rotations. An example of this is afforded by the Pennsylvania Experiment Station data in a rotation of corn, oats, wheat and clover growing on a naturally productive residual limestone clay loam soil, of the Hagerstown series. The yields follow:

TABLE XL

Rotation without Manure or Fertilizers (Pennsylvania)

Total Acre Produce of Corn, Oats, Wheat and Clover

Rotation	Pounds
First	14,681
Second	14,343
Third	12,612
Fourth	9,563
Fifth	9,817
Sixth	8,837
Seventh	8,957

* Average unfertilized yields for the entire period 1882 1916 have been 38 8 bushels of corn, 31 5 of oats, 13 5 of wheat and 26 0 cwt of clover

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CHAPTER XV

THE CONSERVATION OF SOIL NITROGEN

While the average soil contains about 3500 pounds of nitrogen per acre to plow depth, with smaller percentages in the subsoil, the air above each acre is estimated to contain seventy million pounds of this element. This is available for use by plants, assuming that advantage is taken of the capacity of nitrogen fixing organisms to change it from the gaseous to the combined state from which it may subsequently be liberated for the use of crops in the nitrification process. The economy of soil nitrogen presents a peculiar problem in another way by reason of the solubility of the nitrates and their tendency to be leached from the soil. There is a further complication with nitrogen in the possibility of loss through denitrification in which case the element is returned to the air in the elemental state. Such losses are probably somewhat limited and yet they may occur under anaerobic conditions. It is generally assumed that if the problem of nitrogen economy has been solved the problem of soil management has been very materially simplified.

COMBINED NITROGEN IN RAINWATER

Liebig was of the opinion originally that the ammonia of the atmosphere served to renew the nitrogen of the soil. Lawes and Gilbert's controversies with Liebig were, among others, concerning this point. They subsequently found that the total combined nitrogen in the rainfall at Rothamsted amounted to only from 3 to 5 pounds per acre annually. A review of these and subsequent investigations on this

subject, by Wilson, indicates that in some cases the amount of nitrogen from this source may even be as much as 10 or 15 pounds per acre, the quantity being probably related to the rainfall and to the nearness of industrial plants consuming large amounts of coal. At Wooster, Ohio, the nitrogen content of the rainwater has been from 6 to 7 pounds yearly, with a rainfall of 37.9 inches. Such amounts, while inadequate to compensate for losses occasioned in the removal of crops, serve as a supplemental source of nitrogen sufficiently large to have considerable influence in the economy of nitrogen over a period of years.

EXPLANATION OF VALUE OF LEGUMES IN ROTATION

The good effect of legumes on the crops which follow has long been known. Lawes and Gilbert early discovered that legumes contained relatively high percentages of nitrogen. It was generally assumed that they functioned in some way as agents for the renewal of the nitrogen in the soil, but evidence of their nitrogen-fixing capacity was wanting. A considerable amount of investigational work was conducted by Lawes, Gilbert and Pugh at Rothamsted, by Boussingault in France, by Atwater in Connecticut and by Hellriegel and Wilfarth in Germany. The final proof that nitrogen fixation was a function of the nodule organism was announced by Hellriegel before a meeting of research chemists held in Berlin in 1886. In this report it was shown that all that was needed to make a legume grow on a sandy soil containing little or no nitrogen was the presence of the mineral elements and an extract from a soil which had previously grown this legume. All of the plants which grew successfully under such conditions carried nodules on their roots. Subsequently it was discovered that it was not essential that the Bacillus radicicola be associated with legumes to fix nitrogen but that this cooperative arrangement increased their efficiency.

Very carefully controlled tests have shown that nitro-

gen fixation is not a function of the leaves of legumes but that it is accomplished solely by the nodule bacteria. The nature of the first nitrogen product synthesized is not known but ammonia and asparagin have been suggested. Once the nitrogen is built into protein combinations in the nodule organisms or the legume, it is probably available to other crops only through nitrification. As to whether any associated non-legumes are benefited by nitrogen fixed by the nodule organisms is uncertain. While the content of the nitrogen of the associated non-legumes has been shown to be increased, this may be by reason of the favorable effect of the legume on nitrification.

INOCULATION OF LEGUMES

In Hellriegel and Wilfarth's experiments it was noted that inoculation was not accomplished in certain cases unless the soil extract was secured from a soil on which the particular legume had been previously grown. After some years of investigation of this problem, the conclusion has been reached that there are either several species of the nodule organisms or that, by reason of their long association with the different species of legumes, they have become adapted only to the species or family with which they have been associated in nodule formation. For this reason it is quite common to find examples of failures of legume crops for which no explanation is available except that they are new to the field in which they are planted and that the necessary species or adaptation forms of nodule organisms are absent from the soil. The difficulty has often been overcome by the use of soil taken from a field on which that species of legume has been grown previously, or of inoculating material prepared from pure cultures of the organisms secured from the nodules of the same legume species. The success of artificial inoculation has been such that legume failures are often credited to lack of inoculation when the limiting factor may have been insufficient phos-

phate or carbonate of lime, inadequate drainage or perhaps the presence of some disease.

Ordinarily, successful inoculation may be accomplished by sowing a few hundred pounds of soil per acre or by moistening the seed with a suspension of the inoculated soil in water. At times it is more convenient to use commercial cultures, many of which have been found to be reliable. The United States Department of Agriculture and several of the state experiment stations have been distributing pure cultures of nodule organisms to farmers at cost. A number of commercial concerns also produce them for sale. A variety of culture media have been suggested for use in connection with the growth and distribution of these cultures of which the following is an example of one which has proven satisfactory:

Culture Solution for Legume Bacteria

Tap water	1000 c c
Potassium phosphate	1 gr
Magnesium sulphate	0 2 gr
Cane sugar	10 gr

EFFECT OF ACID SOILS ON NODULE BACTERIA

In the above solution the reaction is adjusted ordinarily to approximately the neutral point. The effect of acidity on the nodule organisms varies with the species or strain. In general their sensitiveness to acid soil conditions is believed to correspond to that of the several legumes on which they produce nodules. Among the more recent investigations of this point is that of Fred and Davenport who classify certain of the nitrogen fixing organisms with reference to their critical acidity as shown in Table XLI.

The nodule organisms are known to continue to live in the soil for some time after the associated legume has been grown. If the soil remains in a condition suitable for the growth of that species of legume, the nodule organisms will probably survive in the soil for an indefinite period. If

TABLE XLI

RELATIVE SENSITIVENESS OF NITROGEN ASSIMILATING BACTERIA TO ACIDITY. (FRED.)

Groups of Bacteria	Sensitiveness to Acidity	Critical pH
Alfalfa and sweet clover	Most sensitive	4.8
Garden pea, field pea and vetch	More sensitive	4.6
Red clover and common beans	Sensitive	4.1
Soybeans and velvet bean	Less sensitive	3.2
Lupine	Least sensitive	3.1
Azotobacter	Extremely sensitive	6.1

the legume has been grown but later fails by reason of the lack of carbonate of lime, the corresponding nodule organisms may also have to be supplied before another crop of the same legume can be grown most successfully. The virulence of the organism is probably increased by frequent association with the legume.

CROSS INOCULATION

The question of cross inoculation has not been entirely settled, but the legumes can be arranged in groups with reference to the ease with which their associated nodule organisms inoculate each other. The following classification is that of Burrill and Hansen who divided the legumes studied into eleven groups of which seven are shown in the table below as containing those most commonly grown:

TABLE XLII

CROSS INOCULATING GROUPS OF LEGUMES (BURRILL AND HANSEN)

1	Red, mammoth, alsike, crimson and white clovers
2	Sweet clover and alfalfa
3	Cowpea, Japan clover and peanut
4	Garden and field peas; vetch and sweet pea
5	Soybean
6	Garden bean
7	Black locust

INOCULATION OF NON-LEGUMES

Occasionally inquiries are received, probably inspired by those dealing in inoculating materials, concerning the growth of nodules on the roots of such crops as corn. The most notable experiment along this line is that reported by the Illinois Station in which a study was made of the organisms which live in the nodules commonly found on some of the non-legumes. The conclusion was reached that these nodules were not produced by nitrogen-fixing organisms.

In 1893, Schneider, at the Illinois Station, cultivated some bacteria, secured from nodules of the common bean, upon bean extract agar and then upon a mixture of bean extract and corn extract and finally upon corn extract agar alone. An attempt was then made to grow nodules on corn and oats. The inoculated corn and oats plants produced no nodules although Schneider claimed that they were more thrifty than the uninoculated plants.

Attempts were made likewise to produce nodules on tomatoes, strawberries and morning glory plants by the use of bacteria which had been secured from sweet clover nodules and grown on tomato stem slants. Other specimens of these slants were inoculated with composite cultures from nodules of 45 different legume species. In no case was there any apparent effect. While such experiments may in time be successful, the present indications are that such a result is improbable.

INOCULATION WITH AZOTOBACTER

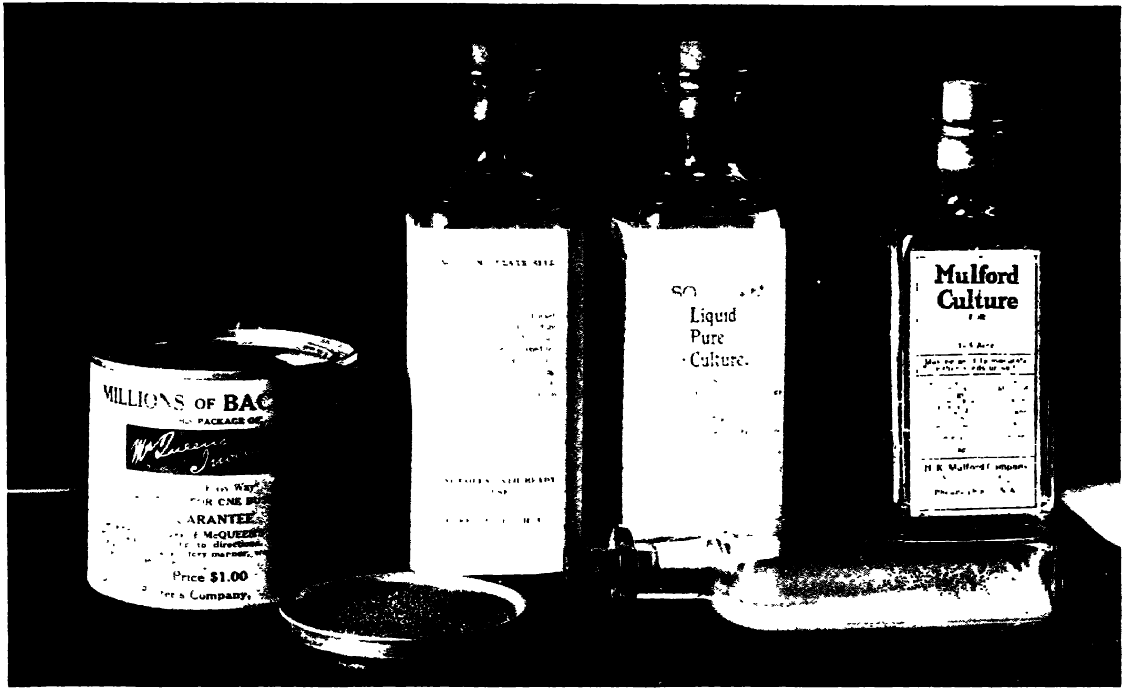
As a rule, inoculation of the soil with non-symbiotic nitrogen-fixing organisms has not been shown to have any very beneficial effect, although some exceptions to this have been noted. It is probable that best results could be expected from such inoculation on recently limed soils in which the Azotobacter had been weakened or destroyed as

a result of acid soil conditions. However, most acid soils contain neutral areas or occasional particles of limestone which probably serve as centers of infection for Azotobacter as well as nodule organisms. When such soils are limed, these organisms on being distributed during the processes of cultivation may reinoculate the entire mass of soil.

QUANTITIES OF NITROGEN FIXED BY NODULE BACTERIA

There has been considerable speculation concerning the nitrogen-fixing capacity of legumes and their associated nodule organisms. A statement of Hopkins, which has been frequently misquoted, credits " not more " than two-thirds of the nitrogen of red clover to the air and one-third to the soil. The " not more " is usually omitted. On the assumption that the proportions indicated obtain, Hopkins points out that if a crop of clover was grown and removed from the field, the soil would neither gain nor lose in its nitrogen content. This assumption is based on the evidence of the Delaware Experiment Station which indicated that of the total nitrogen of the clover plant one-third is to be found in the roots and stubble and two-thirds in the harvested crop. If the clover crop was plowed under, the gain in nitrogen on the basis of this assumption would be 40 pounds for each ton of clover hay produced. If the clover was fed and the residue returned as manure, the gain would be 32 pounds per ton of hay, assuming an 80 per cent nitrogen recovery in the manure.

Such a simple statement of the quantitative effects of the clover crop on the nitrogen content of the soil is likely to be far from the truth in many cases. Hellriegel and Wilfarth's original experiments had shown that the entire nitrogen requirements of legumes could be satisfied from the air when they were grown on nitrogen-free sand. Subsequent studies have made it apparent that in the presence of available nitrogen in the soil neither the symbiotic nor the non-symbiotic groups are likely to secure all of their



Soil Liquid Agar

Fig. 16.—"Inoculation of a legume can be accomplished by the use of soil taken from a field on which that species of legume has been previously grown or of inoculating material prepared from pure cultures of the organisms secured from the nodules of that species of legume."

nitrogen from the air. The rate of fixation, therefore, is determined not only by the extent to which conditions have been made favorable for the growth of the legume and its supporting organisms, but also by the extent to which their nitrogen requirements are satisfied by that made available by nitrification in the soil.

SOME POT EXPERIMENTS ON NITROGEN FIXATION

An interesting and suggestive study of the quantitative fixation of nitrogen under optimum conditions is found in the pot experiments of Hartwell and Pember. In these tests five crops each of cowpeas and soybeans were grown in two different sets of pots with vetch as a winter cover crop. The summer legumes were harvested and removed and the cover crops were turned under. The following table gives a summary of the data calculated in terms of an acre of soil:

TABLE XLIII

FIVE-YEAR POT EXPERIMENTS ON NITROGEN FIXATION (RHODE ISLAND)

Legumes as Summer Crops—Vetch as Winter Cover Turned Under

Nitrogen Content	Pounds of Nitrogen per Acre of Soil	
	Soybeans	Cowpeas
In soil at beginning....	3641	3471
In planted seeds .. .	600	265
In added manure and water	71	72
In aerial portion of legumes .	1310	1170
In soil at end of test	1820	1192
Gain in nitrogen in 5 years	1845	2154

Under conditions suitable for pot tests the non-symbiotic fixation is also favored so that the division of the credit as among the several groups of organisms is very difficult. It would be interesting to continue such an experiment for a longer period in order to determine the point at which nitrogen fixation would cease by reason of the abundance

of available nitrogen in the soil. Fixation in the above test was at a rate of 200 pounds for each legume crop, a considerable part of which may have been accumulated by the non-symbiotic groups.

EFFECT OF INOCULATION ON YIELD AND NITROGEN CONTENT OF LEGUMES

A method of estimating the amount of nitrogen fixed by the nodule bacteria, which has been employed frequently, is that of comparing the nitrogen content of inoculated and uninoculated legumes grown on equal areas of land and calculating the data on the acre basis. An example of such a comparison is selected from data reported by Fred on soybeans grown on Plainfield sand on which no legumes had been seeded for at least twenty years previously. The data follow:

TABLE XLIV

THE INCREASE IN YIELD AND THE AMOUNT OF NITROGEN FIXED AS A RESULT OF INOCULATION OF SOYBEANS GROWN ON PLAINFIELD SAND

Yield	Yield Calculated on Acre Basis			
	Tops, Pounds	Roots, Pounds	Nodules, Pounds	Total Pounds
With bacteria	2598	197	115	2910
Without bacteria	811	145	0	956
Gain due to inoculation	1787	52	115	1954
Nitrogen Content	**Nitrogen Calculated on Acre Basis**			
	Tops, Pounds	Roots, Pounds	Nodules, Pounds	Total Pounds
With bacteria	57.1	2.4	5.8	65.3
Without bacteria	7.4	0.8	0	8.3
Gain due to inoculation	49.7	1.6	5.8	57.0

LOSS OF NITRATES IN DRAINAGE

Under field conditions there is considerable opportunity for the loss of nitrates in the drainage water. The most reliable data on such losses are to be found in lysimeter tests of which those of Lyon and Bizzell at Cornell are typical. Soil was transferred from the field to the lysimeters with as little disturbance as possible, the several horizons of soil being replaced as they occurred in the field. The data in these tests indicate that the quantity of available nitrogen is quite definitely related to the crop and its influence on nitrification. The losses are reduced to a minimum where a crop is kept growing on the soil. Data on drainage losses of nitrogen from Dunkirk clay loam soil having a nitrogen content of 0.134 per cent in the surface foot of soil, and Volusia silt loam soil having a nitrogen content of 0.145 per cent in the surface foot follow:

TABLE XLV

DRAINAGE LOSSES OF NITROGEN AS RELATED TO CROPPING SYSTEM (CORNELL)
Pounds of Nitrogen per Acre in Crops and Drainage Annually

Crops	Dunkirk Clay Loam Soil		Volusia Silt Loam Soil	
	In Crops	In Drainage	In Crops	In Drainage
Maize	144	12	32	15
Oats	73	9	29	10
Mixed grasses	16	1		
Timothy	19	3		
Timothy and clover	73	2		
Peas			81	12
Bare tanks .		93		54

THE SOLUTION OF THE NITROGEN PROBLEM

The solution of the nitrogen problem lies in the conservation of the nitrogen compounds in the soil by prevention of drainage losses; in the return of that contained in the

manure of the animals fed on the crops grown; and in supplementing the combined nitrogen in the soil with that secured from the air by taking advantage of the nitrogen fixing capacity of the symbiotic and non-symbiotic organisms in the soil. The very prominent part played by the nitrogen-fixation agencies is apparent. It is especially necessary that advantage be taken of these agencies in those cropping systems in which the acre values of the crops are not such as to permit of supplying the nitrogen requirements in the form of fertilizers. Under favorable conditions nitrogen fixation must be quite rapid and sufficient to satisfy the requirements of large yields. The organisms having to do with fixation are apparently benefited by those practices which are ordinarily employed to increase the yield of most crop plants. Application of limestone and of phosphate and potash fertilizers, the plowing under of organic matter, and the use of tile drains may be effective by reason of their stimulation of nitrogen fixation in the soil as well as from their direct effect on the crops.

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CHAPTER XVI

MINERAL ECONOMY IN SOILS

THE application of the " bank account " system to the nitrogen and mineral resources of the soil is found to be unsatisfactory in a number of ways. Ordinarily this has called for an inventory of " deposits " by means of chemical analysis for total constituents and a record of the " checking " losses sustained in the removal of the soil elements in crops and drainage. Often the soil resources are presented in terms of the number of pounds of each element estimated to be in the plow depth of an acre of the soil in question. It is recognized, however, that the roots of most of the ordinary farm crops penetrate the soil to a depth of several feet and that possibly under favorable conditions a considerable part of the mineral requirements of crops may be secured from the subsoil. Deep-rooted legumes, for example, are often grown with difficulty on soils having an acid reaction, but if once the roots have penetrated into a subsoil which contains a fair amount of carbonate of lime a marked improvement in the crop is noted.

ESSENTIAL ELEMENTS IN THE SUBSOIL

Considering only the elements commonly supplied in the form of fertilizers and in limestone, it is interesting to note the quantities of these in successive depths of soil and subsoil. An example is given by Hopkins which will afford some idea of what is to be expected in the glaciated soils of Illinois.

TABLE XLVI

AVERAGE ANALYSES OF TWENTY ILLINOIS SOILS
Calculated in Pounds per Two Million Pounds of Soil and Subsoil

Depth	Weight of Soil	Nitrogen	Phosphorus	Potassium	Limestone
0 – 6⅔ in	2,000,000	4,051	1,155	33,652	1,719
6⅔–20 in	4,000,000	2,218	991	34,471	1,340
20 –40 in	6,000,000	504	508	17,360	8,900
Total, 40 in.	12,000,000	10,002	1,667	151,680	31,099

AGENCIES EFFECTING RENEWAL OF SURFACE SOIL

Liebig's " mineral theory " states that " the crops on a field diminish or increase in exact proportion to the diminution or increase of the mineral substance conveyed to it in manure." Whitney, in considering the application of this theory in American teachings and practice, came to the conclusion that it was being interpreted too literally. It was his opinion that the resources of the soil were practically inexhaustible and that certain compensatory processes were in operation which would serve under good management to renew the soil elements required for plant growth as rapidly as they were removed. Among these were mentioned the fixation of atmospheric nitrogen; the upward movement of soluble salts in plants and in capillary water; the action of burrowing worms and insects and the effects of erosion.

PLANTS AS SOIL RENEWING AGENTS

In the table of analyses of Illinois soils and subsoils the nitrogen and phosphorus are shown to be more concentrated in the surface soils. The explanation of this in the case of nitrogen has previously been given and lies in the fact that nitrogen-fixation processes are largely aerobic. There is also a tendency for the accumulation of phosphorus

and nitrogen in the surface soil by reason of their having been utilized by plants and left behind in their residues in the surface soil. Plants secure the element phosphorus, at least in part, from the subsoil and its translocation to the surface of the soil is through the plant. Similarly it would seem that others of the necessary mineral elements might be secured from the subsurface and subsoil and left behind in the surface soil in plant remains. This suggests the use of deep-rooted crops in the rotation as a means of utilizing the mineral elements in the subsoil.

PLANTS AS SOIL CONSERVING AGENTS

It has been shown that the losses of elements in the drainage water may be very considerably reduced by keeping the soil covered with vegetation. As to whether this will result in the conservation of the mineral elements will be determined by the extent to which the crops themselves are returned as such, or in the form of manure, to the soil. The roots and stubble of crops should in any case function as conservers of a part of the total amounts of the several elements saved from drainage by the crops.

TABLE XLVII

EFFECT OF CROPPING ON LOSSES OF MINERAL ELEMENTS BY DRAINAGE. LYSIMETER TESTS—MANURED DUNKIRK CLAY LOAM SOIL

Average Annual Loss of Elements in Pounds per Acre

Element	From Bare Soil	From Planted Soil	Removed in Crops
Calcium	367	173	13
Sodium	103	78	9
Nitrogen	93	5	77
Magnesium	65	37	7
Potassium . .	61	16	79
Sulphur	19	38	10
Phosphorus	Trace	Trace	18

A comparison of the losses of soil elements in the drainage from bare and cropped soils is given in the lysimeter data of the Cornell Agricultural Experiment Station as shown in Table XLVII.

The table indicates the extent to which losses of the mineral elements and nitrogen are prevented by growing crops on the soil. A part of this saving is accounted for in the crops removed and an additional amount in their root systems. There is a further saving in the reduction of percolation through the soil since in the experiments indicated this was reduced from over 24 inches to 17 inches when the soil was growing crops. The increased loss of water from the soil through transpiration also tends to give a greater opportunity for the rise of any soluble elements in the subsoil toward the surface by being carried upward in the capillary water.

CAPILLARY MOVEMENT OF SOLUBLE SALTS

The rate of diffusion of soluble salts in soils is slow. They may be carried upward by the capillary water or by gravitational water accompanying a rise in the water table. In this case there will be an accumulation of salts on the surface of the soil unless the upward capillary movement is balanced by a gravitational movement downward. As these salts move through the soil in either direction certain changes in concentration take place as a result of soil absorption. King investigated these changes by supplying a water solution of salts at the base of 24-inch columns of soil, exposing the soils to the action of evaporation, and determining the salt content at various depths of the soil columns at the expiration of periods of from seventeen to twenty days. Additional water was supplied at the bottom of the soil columns to take the place of that lost from the surface by evaporation. The data follow:

TABLE XLVIII

CAPILLARY MOVEMENT OF SALTS IN SOILS IN 17 TO 20 DAYS (KING)
Solution of Salts Supplied at Bottom of 24-inch Soil Columns

	Parts per Million of Ions as Distributed in Soil					
	K	Ca	Mg	NO_3	HPO_4	SO_4
Norfolk Sand:						
0–1 inch below surface	31	300	63	1068	4.8	34
10–12 inches below surface	8	26	10	43	4.3	36
Original soil	15	15	11	46	3.7	40
Selma Silt Loam:						
0–1 inch below surface	65	2125	273	3632	3.3	375
10–12 inches below surface	10	90	11	58	7.1	175
Original soil	16	450	15	201	4.9	95
Hagerstown Clay Loam:						
0–1 inch below surface	28	550	155	1730	9.3	168
10–12 inches below surface	15	108	41	145	10.3	228
Original soil	13	116	33	234	9.9	75
Solution supplied	119	30	41	55	49.9	162

ABSORPTION BY SOILS

The calcium, magnesium and nitrate ions were found to move upward readily with the capillary water. The same was true of the sulphate ion in two of the three soils data for which are shown in the table. The movement of the potassium ion was considerably reduced. With the phosphate ion there was no apparent tendency to concentrate at the surface of the soil although some upward movement was noted, as indicated by the increased concentration of this ion in the soil some distance above the point of contact of the original solution with the soil column.

This tendency of soils to slow down and in some cases almost entirely prevent the movement of ions in solution is referred to as absorption. There has been a considerable

amount of investigation of this phenomenon, but no very definite agreement as to the exact nature of the absorption process. Soluble phosphates are known to be precipitated by aluminium and iron. The phosphate ion appears also to be strongly adsorbed by soils. In the case of potassium the absorption is either a matter of basic exchange or a substitution of the potassium ion for previously adsorbed calcium and magnesium ions. Consideration of the lysimeter tests at Cornell indicates that for every given amount of potassium absorbed by the soil an equivalent amount of calcium and magnesium is to be found in the drainage water. Because of the practical importance of this calcium-potassium relationship, the following table is attached which shows the extent to which these bases were able to replace each other in the soil solution in these lysimeter tests:

TABLE XLIX

AVERAGE ANNUAL LOSS OF BASES IN DRAINAGE WATER (CORNELL)
As Influenced by Applications of Lime and Potassium Sulphate
(Calculated in Pounds per Acre)

Soil Treatment	Calcium	Magnesium	Potassium	Sodium
No fertilizer	177	34	46	84
Potassium sulphate*	213	49	41	84
Burned lime †	170	40	16	73
Both of above	200	47	10	74

* Annual application of 200 pounds of potassium sulphate per acre
† One application of 3000 pounds of burned lime at beginning of test in 1910 Report for 1910–1914 inclusive

It will be noted that neither calcium oxide nor potassium sulphate applications increased the quantity of potassium in the drainage water. On the other hand, applications of potassium sulphate did increase the content of calcium in the drainage water. A consideration of the combined amounts of magnesium and calcium in the drainage indicates that the two are released in amounts approximately equivalent to the potassium supplied.

DRAINAGE LOSSES OF MINERAL ELEMENTS

Any upward movement of salts by capillarity is likely to be overshadowed by a greater movement downward as a result of the action of gravitational water. In semi-arid regions, this would not be true since, under such conditions, water is not lost in any considerable amounts by drainage.

FIG. 17.—"The soil is not a static system but is constantly undergoing change of location of undissolved and dissolved materials. Further, its chemical, as well as its physical and biological composition, also changes as it exists in any given position."

In the humid sections there is every reason to believe that the loss in this manner is considerable, the evidence for this having already been presented in the chapter on the soil reaction. The salt content of river waters in humid sections is of interest in this connection as indicating something as to the relative rates at which the several elements are likely to disappear from the soil. Examples chosen from data by Clarke, in which are shown the composition

of the waters of the Muskingum and Miami Rivers of Ohio, are given below. The former flows through a sandstone-shale area and the latter through a limestone area.

TABLE L

SALT CONTENT OF RIVER WATERS (CLARKE)
Percentages of Total Salinity

	Muskingum River	Miami River
CO_3	24.71	43.64
SO_4	18.36	13.88
Cl	17.07	1.42
NO_3	0.69	2.98
Ca	18.36	20.46
Mg	4.06	8.33
Na	9.39	2.49
K	1.28	.83
SiO_2	5.98	5.89
Fe_2O_3	.10	.08
Total	100.00	100.00
Salinity in p. p. m.	244	289

Phosphorus is present apparently only in traces since it is not mentioned in the table. Potassium and magnesium tend to be retained more than sodium and calcium. Sulphur appears to be leached readily from the soil. With this element the cycle is somewhat similar to that of nitrogen in the fact that sulphur is added to the soil in rainwater. The annual sulphur content of the rainwater at Urbana, Illinois, for example, is given by Stewart at from 40 to 50 pounds per acre from which it appears reasonable to believe that the failure of crops to respond to the use of sulphur in fertilizers in industrial sections is due to this return cycle.

EFFECT OF EARTHWORMS IN RENEWING SOIL

Two other groups of agencies operate to renew the surface soil from the subsoil. In the first group may be included animals which burrow in the soil and transfer the subsoil to the surface. Of these the earthworm is the most universally distributed and most effective. Darwin, in a very interesting book on the subject of "The Formation of Vegetable Mold," attributes a translocation of soil to earthworms amounting to 1 inch in five years. This conclusion is based on observations as to the rate at which such material as stones, supplied to the surface, became imbedded in the soil. The burial of the ruins of ancient cities is credited by Darwin to the action of earthworms. He estimated that as much as 10 tons of material annually pass through the bodies of the earthworms in an acre of soil in certain parts of England. The carrying up of the subsoil would be, according to this, a continual process tending to renew the surface soil.

Observations of soils of the Ohio State University Farm indicate that the number of earthworms in an acre of soil to a depth of 1 foot amount to more than one million. None were found at a greater depth than 1 foot in the soils examined although burrows were found to extend several feet below the surface.

EROSION AS A FACTOR IN SOIL RENEWAL

Probably a more effective group of agencies in the translocation of soil and subsoil, particularly in arid, semiarid and sandy regions and in areas of rolling topography in the humid regions, are those associated with erosion. In either case, whether the soil is covered by wind-blown material or replaced by subsoil as it is removed by water, the effect may be a complete renewal. In areas affected by wind erosion the transfer of soil may be so rapid as to cover the existing soil to a depth of several inches in a few

hours. The most extensive erosion, although somewhat less rapid, is that caused by running water, which is particularly effective on land frequently cultivated. The extent to which the surface soil is removed is determined by the character of the soil, the frequency with which cultivated crops are grown, the climatic conditions and the slope of the land. According to McGee, the rate of erosion of land by water is estimated by geologists at 1 inch for every two hundred to five hundred years. Dole and Stabler calculate that the United States is being denuded at an average rate of 1 inch in 760 years. Lands under cultivation, particularly the silt loams, with only a moderate slope may be expected to be eroded at a rate of an inch or more per century under climatic conditions such as exist in the humid regions of the United States.

An investigation of the losses by erosion under ordinary field conditions is under way at the Missouri Station under the direction of Miller. In these investigations it has been shown that with a slope of perhaps 5 degrees, Shelby loam soil erodes under the weather conditions at Columbia, Missouri, at the following rates:

TABLE LI

ANNUAL RATE OF REMOVAL OF SOIL BY WATER EROSION (MILLER)
Slope of 5 Degrees—Shelby Loam Soil—1917 to 1921

Soil Treatment, Annually	Soil Removed, Tons per Acre	Rainfall Absorbed, Per Cent	Years Required to Remove 7 Inches
Uncultivated, weeds pulled	91	51	39
Cultivated throughout summer	139	72	25
Same with deeper plowing	129	74	27
Continuous sod	1	90	2336
Wheat every year	18	79	193
Three-year rotation	14	81	253
Corn every year	67	76	52

It is evident from the above considerations that the soil is not a static system, but that it is constantly undergoing change of location of undissolved as well as dissolved materials. It is possible to take advantage of certain means of conservation by which the soil can be largely held in place and at the same time have its mineral content gradually renewed from the subsoil. It cannot be said, however, that losses by drainage and erosion are always objectionable, in fact quite the opposite is often true. While it is essential to have in mind the fact that the amounts and availability of the essential mineral elements in the surface soil largely determine its immediate productivity, the dynamic agencies in operation cause difficulty in making a very strict application of the "bank account" system to the soil resources, particularly if the inventory is confined to the plow depth of soil.

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CHAPTER XVII

LIMESTONE ECONOMY IN SOILS

THE rapidly increasing area of acid soils in the humid regions of the United States makes the problem of maintaining the soil reaction at a point suited to the needs of the crops ordinarily grown a rather serious one. The usual recommendation in general farming practice in the Central West, once the soil is acid, is that limestone be supplied to the soil in quantities sufficient to bring the soil reaction approximately to the neutral point and then to maintain it at this point by the regular use of limestone at some definite time in the rotation, or perhaps every second rotation. It has usually been assumed that the amount of limestone necessary to be applied to maintain the soil reaction at this point would amount to 1 ton per acre every three to five years. Thus Stewart suggests 1 ton per acre every three or four years for the prairie land of Southern Illinois. Other investigators have suggested similar amounts. On the assumption that such amounts will be needed, a 160-acre farm would require a carload of limestone annually. Applied at this rate to the entire area of land in the humid section in the United States, a large percentage of which is already acid, this means an enormous tonnage of this material.

LIME-REQUIREMENT OF PLANTS

In an interesting discussion concerning the utilization of acid land for the growth of acid tolerant crops, Coville points out that " soil acidity is not always an objectionable condition which invariably requires lime." It is his opin-

ion that "under certain conditions a complete system of acid agriculture is practicable." While there is some question as to whether a very high type of agriculture could be developed without the use of limestone on acid soils, it has been shown that crops differ very materially in their lime requirements. Truog has arranged the common agricultural plants according to their need for lime as the bicarbonate. He takes into consideration the calcium content of the plant, its rate of growth and the extent and character of its root system. The following table is a summarized grouping of the more common crops according to Truog's arrangement:

TABLE LII

Relative Lime-Requirements of Crops (Truog)

Index Number	Crops
5	Alfalfa
4	Sweet clover
3½	Red clover, barley
3	Soybeans
2½	Alsike, vetch, timothy, potatoes, corn
2	Wheat, buckwheat, crimson clover
1½	Lupines, oats
1	Sheep sorrel, red top, rye, cranberry

RESPONSE OF CROPS TO LIMING

A considerable part of the data from which Truog reached his conclusions on the lime-requirements of crops was taken from the work of Hartwell and Damon, who had studied the response to liming the soil of 280 different varieties of plants when grown on an acid soil at the Rhode Island Experiment Station. In these studies four large plots were used, all of which received liberal applications of fertilizer, containing its nitrogen in two cases in the

form of sulphate of ammonia and in the other two cases as nitrate of soda. The test had been under way at the time of publication of the data for a period of twenty-two years. Arranging the common agricultural crops on the basis of their response to liming the soil shows the following:*

TABLE LIII

RESPONSE OF PLANTS TO LIMING AN ACID SOIL (RHODE ISLAND)

Index Numbers Indicating Relative Response

−1	0	1	2	3
Peanut	Beans	Buckwheat	Cabbage	Asparagus
Sorrel	Corn	Carrots	Cauliflower	Barley
Watermelon	Cotton	Oats	Chard	Beets
Serradella	Cowpea	Peas	Egg Plant	Celery
	Lupines	Pumpkins	Hemp	Lettuce
	Potato	Rhubarb	Horseradish	Onions
	Rye	Wheat	Muskmelon	Spinach
	Vetch	Cucumbers	Rape	Tobacco

It will be noted that not only were some of the crops not benefited by liming, but that a few were actually injured. It is desirable in this connection to consider how acid the soil used in these experiments was. The method originally employed in determining the acid condition of the soil was that of Veitch. This method measures the lime-absorbing capacity of the soil up to a point at which hydrolysis will yield a solution which is alkaline to phenolphthalein. The lime-absorbing capacity of soils by this method is found to vary considerably with the conditions under which the laboratory manipulations are carried out.

The data show that at the end of the twenty-second year of the test the sulphate of ammonia plot had a lime-absorbing capacity, figured as calcium carbonate, of 9000 and 5300 pounds, respectively, for the unlimed and limed ends. Similarly the nitrate of soda plot had a lime-absorb-

ing capacity of 4800 and 3600 pounds, respectively, on the unlimed and limed ends. Later it was found necessary to add lime to the previously unlimed sulphate of ammonia plot in order to have any growth of vegetation on it. A total of 1 ton of burned lime per acre was applied to this plot. Subsequently the soil on this plot was shown to have

FIG. 18.—"The rapidly increasing area of acid soils in the humid regions of the United States makes the problem of maintaining the soil reaction at a point suited to the needs of the crops ordinarily grown a rather serious one." (Courtesy, Ohio Marble Company.)

a *p*H of 4.62 as an average for the summer of 1921 while that on the unlimed nitrate of soda plot had an average *p*H for the same period of 5.24.

LIME-ABSORBING CAPACITIES OF ACID SOILS

The question naturally arises as to how acid soils may become under ordinary systems of farming in which little or no limestone is applied. Of interest in this connection is the report of the analyses of 232 samples of West Virginia soils, as recorded by Salter and Wells, in which the lime-absorbing capacities of these soils by the Veitch method are given. These samples of soil were chosen from widely

distributed points in the state and represent a considerable number of soil types. A summary of the data obtained is given below:

TABLE LIV

LIME-ABSORBING CAPACITIES OF 232 WEST VIRGINIA SOILS

$CaCO_3$ per Two Million Pounds of Soil (Veitch Method)

Group	Number Samples in Group	Average Lime-Absorbing Capacity
1	41	0
2	21	0–1000
3	61	1000–2000
4	61	2000–3000
5	21	3000–4000
6	7	4000–5000
7	11	5000 up

It will be noted that a large percentage of these soils have a lime-absorbing capacity by the Veitch method of less than 4000 pounds of calcium carbonate per two million pounds of soil. This is approximately that of the limed nitrate of soda plot on the Rhode Island Experiment Station farm on which a considerable variety of crops have been growing satisfactorily. Apparently the acid condition in mineral soils comes to equilibrium at a deficiency of calcium carbonate (Veitch method) ordinarily amounting to from 1000 to 4000 pounds per acre to plow depth. Similarly the *p*H of acid soils usually has been found to be between 5 and 6, a hydrogen ion concentration which is probably not directly injurious to many crop plants. It seems probable that it would be considerably less difficult to maintain the soil at this reaction than at a point more nearly approaching neutrality.

ACID AGRICULTURE POSSIBILITIES

Truog believes the so-called acid agriculture may be desirable under certain conditions, but that with the development of more intensive and highly specialized cropping systems the crops of medium and high lime-requirements will be grown in preference. He suggests the following grouping of crops as determined by the condition as to reaction at which the soil is to be kept:

TABLE LV

HIGH, MEDIUM AND LOW LIME-REQUIREMENT CROPPING SYSTEMS (TRUOG)

High	Medium	Low Northern	Low Southern
Alfalfa	Red clover	Soybeans	Cowpeas
Sugar beets	Soybeans	Alsike clover	Velvet beans
Canning peas	Timothy	Vetch	Crimson clover
Tobacco	Barley	Cowpeas	Cotton
Cabbage	Wheat	Red top	Corn
Onions	Corn	Millet	Oats
Most garden crops	Oats	Rye	Sugar cane
Sweet clover	Rye	Oats	Japan clover
Bluegrass	Potatoes	Buckwheat	Rye

It will be noted that certain crops occur in both low and medium lime-requirement groups. This is for the reason that their tolerance for acid soil conditions permits a fair growth on such soils, but they also respond to liming. Truog also calls attention to the fact that the more active weathering processes in the southern states makes more of the basic elements available and permits of growing crops with a smaller use of limestone.

ACID SOILS IN RELATION TO NITROGEN ECONOMY

The soil reaction would of necessity have some bearing on the nitrogen economy. The assumption is that those legumes which grow well on acid soils will support the cor-

responding variety of nodule organisms and that they will be able to function satisfactorily. There is the necessity of considering also the other groups of soil organisms concerned with nitrogen fixation and nitrification in soils. Bear studied in a preliminary way the efficiency of some of the organisms concerned in the nitrogen cycle, in two acid soils to which varying amounts of carbonate of lime were applied up to and beyond the lime-absorbing capacities (Veitch) of these soils. In each case the factors other than limestone were kept under control at an assumed optimum. The usual methods of studying the rate of ammonification, nitrification and nitrogen fixation were employed. A summary of the data on the Wooster silt loam soil follows:

TABLE LVI

EFFICIENCY OF NITROGEN CYCLE ORGANISMS IN ACID SOIL
Percentage Efficiency to that in Neutral Soil

Limestone Applied, Pounds per Acre	Ammonification of Casein	Nitrification of Ammonium Carbonate	Nitrogen Fixation Non-Symbiotic
0	57	50	16
250	52	53	30
500	55	56	30
1,000	60	57	38
2,000	82	77	32
3,000	86	83	91
Neutral Point (Veitch)			
4,000	100	100	100
5,000	113	125	106
7,500	100	109	132
10,000	112	107	83

Non-symbiotic nitrogen fixation was very much retarded in the acid soil. There was also a reduction in the efficiency

of the nitrifying bacteria although not so marked in the case of ammonia as in nitrate production.

ECONOMIZING ON LIME

In economizing on lime there are, in addition to choosing plants which can grow on acid soils, certain opportunities to prevent unnecessary losses from the soil. The lysimeter drainage at Cornell, as previously shown, contained less calcium when the soil was cropped. Such lime as is removed in crops can be returned to the soil in large part in the manure on a well-organized livestock farm. Legumes usually contain considerably larger amounts of calcium per ton of produce than do most of the non-legumes. Their growth and removal from the soil increases the rate of depletion of the element calcium unless they are fed and returned as manure. There is also opportunity for choice among fertilizer materials. Phosphorus is always supplied in combination with calcium, and the quantity, of the latter, varies with the several carriers. Thus basic slag has considerable value as a neutralizing agent in acid soils, having an efficiency equal to about half that of an equal weight of limestone. Bone meal carries more calcium than acid phosphate although the latter may be somewhat more efficient as a precipitating agent for aluminium. Sulphate of ammonia leaves an acid residue as contrasted to the alkaline residue of nitrate of soda. Organic carriers of nitrogen lie between nitrate of soda and sulphate of ammonia in their effect on the soil reaction. Wood ashes carry calcium and potassium in the form of their oxides or carbonates.

By economizing on the calcium in the soil, and by a proper choice of fertilizers in connection with a judicious selection of crops, it should be possible to develop a system of cropping in which the amount of lime necessary to apply would be considerably reduced. It might be possible also to grow a clover crop in the rotation on a somewhat acid

soil, by adding a few hundred pounds of finely divided limestone or of burned lime to the grain crop in which it was seeded, and following the clover with such other crops as are tolerant of acid soil conditions. Alfalfa, if desired, could be grown on a separate tract of land which was especially prepared for the crop, instead of attempting to fit it into a rotation the other members of which had considerably lower lime-requirements. As previously indicated, it will be desirable in the more intensive systems of farming to apply lime in sufficient amounts to prevent its being in any way a limiting factor in crop growth. With specialized crops of high acre value there is little need for considering the question of lime economy. On cheap land, or on land inconvenient to the source of limestone, conservation of lime is essential. In any system of ordinary cropping it merits consideration as one of the means of economizing in the production of crops.

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CHAPTER XVIII

ANIMAL MANURES

THE livestock system of farming is one in the best-developed forms of which there may be little loss of the essential soil elements from the farm. This is especially true on those farms on which a large acreage of legumes is grown; where supplemental concentrated feeds are purchased; and where the manure produced is carefully preserved and systematically applied to the fields. Unfortunately, on a large percentage of the livestock farms, the possibilities in the economy of soil elements are far from being realized.

NITROGEN AND MINERAL REQUIREMENTS OF ANIMALS

The amounts of nitrogen, phosphorus and ash elements required in the production of the animal body have been determined by a number of investigators. Of these the recent work of Trowbridge and his co-workers is illustrative. In their investigations the entire carcasses of a number of beef cattle were analyzed. From these analyses the following data were selected:

TABLE LVII

NITROGEN AND MINERAL CONTENT OF BEEF CATTLE (TROWBRIDGE)

Animal	Live Weight Pounds	Pounds of Elements per Animal		
		Nitrogen	Phosphorus	Ash
1	755	22.1	8.1	43.0
2	1061	29.5	8.1	49.6
3	1255	31.5	9.3	52.0
4	1785	35.9	11.1	61.6
Average per 1000 pounds.		24.5	7.6	42.4

The major portion of the ash of animal bodies is made up of calcium and phosphorus as the tri-calcium phosphate in which these elements occur in the ratio of approximately two to one. For every thousand pounds of live weight of animal produced on the farm there are tied up in its body approximately 25 pounds of nitrogen, 7½ pounds of phosphorus and 15 pounds of calcium together with relatively small amounts of potassium, magnesium and sulphur.

NITROGEN AND MINERAL CONTENT OF MILK

The composition of milk varies considerably, depending upon the feed and the kind of animal. According to Babcock the average cow's milk contains the following amounts of the several essential soil elements:

TABLE LVIII

NITROGEN AND MINERAL CONTENT OF COW'S MILK (LEACH)
Pounds of Elements per 10,000 Pounds Milk

Element	Pounds
Nitrogen	60
Phosphorus	7 5
Potassium	14
Calcium	10
Total ash	70

The quantities of sulphur and magnesium in milk are considerably less than those of the other elements indicated above, amounting to approximately 1 pound of each per 10,000 pounds of milk.

NITROGEN AND MINERAL CONTENT OF WOOL

The only other animal product which is of any significance in connection with the economy of soil elements is wool. According to Hopkins, wool contains the following

amounts of nitrogen, phosphorus and potassium per thousand pounds:

TABLE LIX

NITROGEN AND MINERAL CONTENT OF WOOL (HOPKINS)
Pounds of Elements per 1000 Pounds of Wool

Element	Unwashed	Washed
Nitrogen	54	92
Phosphorus	0 3	0 8
Potassium	16 5	1 6

As the table indicates, the potassium is largely water soluble and is an excretory product rather than an essential part of the wool fiber.

PERCENTAGE RECOVERY OF SOIL ELEMENTS IN MANURE

Since the animal makes use of a certain percentage of the mineral elements and nitrogen contained in crops which may later be sold from the farm in the form of the animal itself or its products, it is of interest to calculate the percentage recovery of these elements which ordinarily might be expected in the manure. Vivian, in an excellent discussion of this subject, concludes that under average conditions on the farm about 80 per cent of the nitrogen, phosphorus and potassium in the feeds consumed is voided in the animal excrements. This ratio may be assumed to hold also for calcium and sulphur. If the soil elements were lost only in crops, the livestock farmer should be able to make up the 20 per cent loss by growing legumes, by the the use of supplemental concentrated feeds and by drawing on the mineral reserves in the soil. Unfortunately the drainage losses of certain elements from the soil may often be greater than the losses in crops. Furthermore, manure is a perishable product and a considerable portion of the essential elements contained in it may never reach the field.

DISTRIBUTION OF NITROGEN AND MINERAL ELEMENTS IN MANURE

Some idea of the distribution of the soil elements in manure, as between the urine and feces, may be gained from the following table of data taken from the investigations of Forbes and his co-workers. In this work the excretory products of a dry cow were saved and analyzed separately with the following average results:

TABLE LX

DISTRIBUTION OF NITROGEN AND MINERAL ELEMENTS IN MANURE OF DRY COW

Percentages of Total in Urine and Feces

Element	Urine	Feces
Nitrogen	64 1	35 9
Phosphorus	0 6	99 4
Potassium	95 1	4 9
Calcium	0 1	99 9
Magnesium	10 5	89 5
Sulphur	51 4	48 6

Data from experiments with other cows showed some variation in the percentages in the urine and feces. In general the investigations indicate that the major portion of the nitrogen and potassium is to be found in the urine while most of the phosphorus and calcium is excreted in the feces. Studies with pigs indicated a similar distribution except that somewhat more of the phosphorus and sulphur and less of the potassium was present in the urine.

WATER-SOLUBLE CONSTITUENTS IN MANURE

Manure is made up of urine and feces mixed with residues from the feed and bedding. Of interest in considering the possible losses from leaching are the data given by Ames and Gaither on the content and percentage solubil-

ity in water of the nitrogen, phosphorus and potassium in manure. This manure was sampled as it came from the feeding stalls where it had been protected against loss of urine and presumably from hot fermentation.

TABLE LXI

Composition of Manure Fresh from Feeding Stalls (Ames)

Kind of Animal	Nitrogen		Phosphorus		Potassium	
	Per Ton, Pounds	Water Soluble, Per Cent	Per Ton, Pounds	Water Soluble, Per Cent	Per Ton, Pounds	Water Soluble, Per Cent
Horse	13 9	52	2 1	53	12 7	75
Cow	11 1	50	1 9	50	10 1	97
Sheep	28 7	42	4 1	58	20 8	97

As would be expected, there is considerable variation in the composition of manure depending upon the feed, the class of animal, the age and use of the animal and the amount and nature of the bedding. Of particular interest in the table is the fact that 50 per cent or more of the nitrogen and phosphorus, and in some cases almost the entire amount of potassium, was soluble in water and, therefore, subject to loss from leaching.

LOSSES FROM UNPROTECTED MANURE

Ordinarily the losses of mineral elements and nitrogen from the livestock farm in the sale of animals, milk and wool are insignificant in comparison with those which occur in the careless handling of manure. These losses may result from failure to haul the manure to the field; from lack of facilities for conserving the urine; from leaching and from hot fermentation. Even where the value of manure as a crop-producing agent seems to be appreciated, the losses from leaching and hot fermentation are often considerable.

The possibilities of loss from leaching are indicated in the preceding tables. As manure undergoes decomposition an additional amount of each of the soil elements becomes soluble and, if unprotected, may be leached out. It is desirable that manure pass through a "ripening" process before it is applied to the field, but if this is permitted the manure should be stored under cover and on a

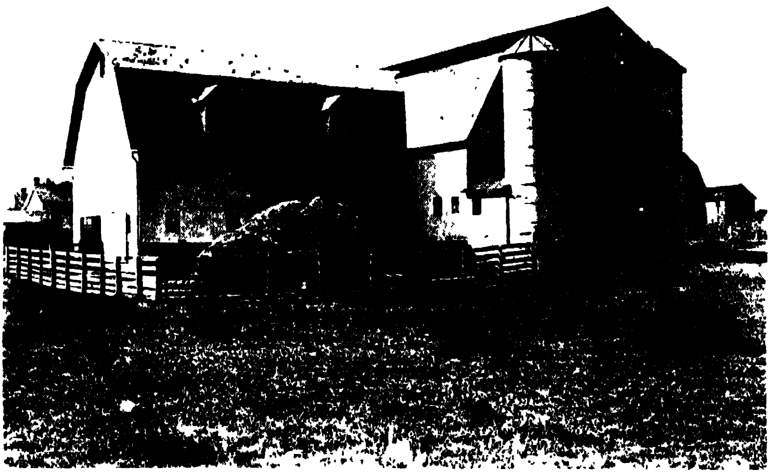

FIG. 19.—"The livestock system of farming is one in the best developed forms of which there may be little loss of the essential soil elements from the farm."

water-tight floor, otherwise more will be lost than gained in the process.

Losses from hot fermentation are brought about in the volatilization of the nitrogen due to rapid oxidation and resulting high temperatures. Horse and sheep manures, by reason of their relatively small content of water, are especially subject to "fire fanging" and for that reason are called "hot manures." The prevention of such losses can be accomplished by keeping the manure wet and com-

pact. Under such conditions, decomposition is more largely anaerobic. The previously insoluble mineral elements and nitrogen in the manure gradually become soluble while the carbonaceous materials are broken down into carbon dioxide and water. In this case there is little loss of ammonia by reason of the concentration of carbon dioxide, in an atmosphere of which, ammonium carbonate is more stable. When such manure is incorporated with the soil the nitrogen of the hydrolyzed protein products is rapidly changed to ammonia and nitrates, conditions being favorable for more rapid oxidation.

Considerable attention has been given to the use of preservatives on manure, but little of definite value from the point of view of practice can be reported. These preservatives are used for the purpose of preventing undesirable types of fermentation or the loss of ammonia by volatilization. Of all the substances employed, acid phosphate seems to be the most important since it combines the capacity to preserve the ammonia and to supply supplemental calcium and phosphorus to the manure, both of which increase its value as a soil-improving agent.

MANURE AS A CROP-PRODUCING AGENT

Remembering that nitrogen can be secured from the air through the growth of legumes, and that it seems possible to return approximately 80 per cent of such of this nitrogen as is contained in the legume hay in the manure produced from feeding it; that soils as a rule contain rather large amounts of potassium; it would seem that by the return of the manure produced from feeding a large portion of the crops it should be possible to maintain the yields of crops at a fairly high level, particularly if the soil was kept supplied with limestone and the manure was supplemented with enough phosphate to make good the loss of this material in bone and milk.

An interesting test of manure as a crop-producing agent

is afforded at the Ohio Agricultural Experiment Station where manure alone and reinforced with phosphates has been used on a limed Wooster silt loam soil for a period of twenty-one years. At the beginning of the test, the soil was not in a high state of productivity and for that reason the average yields are not as high as they might otherwise have been. The yields follow:

TABLE LXII

EFFECT OF EIGHT TONS OF MANURE ON CROP-PRODUCING POWER OF SOIL

Limed Wooster Silt Loam Soil—Rotation Corn, Wheat, Clover

	Twenty-one Year Average Acre Yields		
	Corn, Bu	Wheat, Bu	Clover, Cwt
No manure	35.7	13.7	28.1
Open yard manure	53.9	22.5	35.1
Stall manure	59.8	23.8	41.1
Phosphated manure *	66.8	28.7	49.1

* Acid phosphate applied at rate of 40 pounds per ton of manure

Not only was the stall manure considerably more effective than the open yard manure, but the evidence indicates that fewer tons of manure are available with open yard storage. The addition of acid phosphate further increased the effectiveness of the manure. Unfortunately in this as in most other manure tests of which records are available, the manure used was not that produced from feeding the crops grown on the land to which it was applied, but such manure as was available on the farm from year to year during the period of the test. A somewhat better idea of the possibilities of crop production in the livestock system of farming is to be found in another test, now in progress at Wooster, in which the manure resulting from feeding the

crops to steers is returned to the fields on which the crops fed were produced. The manure is applied to the corn crop in a four-year rotation with soybeans, wheat and clover. All of the crops are fed or used as bedding with the exception of the wheat grain. In addition to the manure, 2 tons of limestone and 700 pounds of acid phosphate per acre are applied every four years.

TABLE LXIII

CROP YIELDS AND MANURE * PRODUCED IN LIVESTOCK SYSTEM OF FARMING

Limestone 4000 lbs., Acid Phosphate 700 lbs., per Acre per Rotation

Crop	Thirteen Year Average Acre Yields	
	Grain, Bu.	Stalks, Cwt.
Corn	68.9	30.5
Soybeans	21.1	21.0
Wheat	34.0	32.1
Clover		11.9

* The manure production has averaged 11.78 tons per acre each rotation.

USE OF SUPPLEMENTAL FEEDS

While supplemental feeds of necessity must come from some other farm, yet the man who purchases them has the opportunity to build up his own soil at the expense of the soil of the farm from which they came. On the livestock farm there is opportunity for choice between buying fertilizers and buying feeds from which to get a supplementary fertilizer value. The following table gives the composition of a few of the concentrated feeds from which can be computed the approximate nitrogen, phosphorus and potassium content of the manure produced from feeding them:

TABLE LXIV

COMPOSITION OF STANDARD CONCENTRATED FEEDS (AMES)
Pounds of Elements per 1000 Pounds of Feed

Feed	Nitrogen	Phosphorus	Potassium
Alfalfa hay	25 1	2 9	16 6
Clover hay	21 7	1 8	11 2
Wheat bran * . . .	21 6	1 2	11 9
Linseed meal * . . .	52 6	7	10 3
Cotton seed meal *	67 8	12 3	12 1
Soybeans	54 3	6 3	18 7
Animal tankage *.	101 0	24 0	4 5

* From Henry and Morrison "Feeds and Feeding"

Ordinarily concentrates are purchased as a source of protein. Their use as feeds with subsequent saving and use of the manure tends to increase the need for supplemental phosphate and limestone.

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CHAPTER XIX

SOIL SANITATION

As soils become older agriculturally they tend to decrease in productivity. In the nomadic period of civilization the solution of the problem of unproductive soils was found in a change of habitation. Later it became desirable to continue to cultivate the same land for an indefinite period and it was then necessary to study the means of overcoming the tendency toward reduction in yields. Jethro Tull, in 1733, was of the opinion that the solution lay in the more intensive cultivation of the soil. Liebig, in 1840, offered a chemical solution based on the theory that plants removed elements from the soil more rapidly than the supply was renewed and that the lack of one or more of these elements in available form became the limiting factor in crop production. This marked the beginning of the fertilizer industry. Later a school of bacteriologists, of which the pioneers were Schloesing and Muntz, Hellriegel and Wilfarth, Winogradski and Beyerinck, offered a bacteriological explanation of soil productivity. Subsequent study has shown that no one of these explanations is adequate, but that the various physical, chemical and biological factors are interrelated and may operate either positively or negatively.

SOME NEGATIVE CHEMICAL FACTORS

Examples of certain negative chemical factors have been given in connection with the problem of acid soils. It will be recalled that it has been shown that the aluminium

which becomes soluble in such soils is toxic to crops. Other examples of metallic toxins are found in arsenic, lead and zinc which may be soil contaminating agents in the vicinity of smelters. Consideration of the soil solution showed that its reaction, the ratios in which the various ions are present and the total concentration of salts, unless kept within fairly narrow limits, may operate as negative factors in relation to the productivity of soils.

NEGATIVE BIOLOGICAL FACTORS

The negative factors with which this chapter is most concerned as related to soil sanitation are biological in nature and include such agents as plant diseases, insects and weeds. The control of these factors may affect, in one way or another, the policy of the farmer in connection with his system of soil management. It is for this reason that crop rotation has received so much attention. Rotation not only has the effect of regulating the available quantities of the several essential elements in the soil, but also provides a means of holding in check certain of these negative biological factors. With more intensive cultivation it has been found necessary to take especial precautions to control plant parasites which live in the soil, both by prevention of unnecessary contamination of the soil and by checking their abnormal development when present in the soil. In this, various methods have been employed such as sterilization by heat and antiseptics, control of the soil reaction and the development of disease resistant strains of crops.

A SANITARY REASON FOR CROP ROTATION

Of considerable interest in this connection is the point of view expressed by Bolley, who has called attention to the problem of soil sanitation in relation to the growing of wheat under the continuous cropping system practiced in the Dakotas. It is his opinion that the explanation of

the reduction in yields, which is commonly experienced under such conditions, is to be found in the accumulation of parasitic organisms in the soil which attack not only the above ground portion of the wheat plants, but also their roots. Bolley believes that the good effects of proper tillage, crop rotation and the use of fertilizers and lime are often indirect in that they serve as means of control of parasitic organisms either by making conditions unfavorable for

FIG. 20.—"With more intensive cultivation it has been found necessary to take especial precaution to control plant parasites which live in the soil." Effect of Cabbage Yellows. (Courtesy, Wisconsin Experiment Station.)

the parasites or especially favorable for the hosts, thereby enabling the latter to resist the invasion of the parasites.

The virulence of parasitic bacteria is often found to be related to the frequency with which they have opportunity to live within the tissues of the host. Crop rotation is a means of reducing this frequency. One of the popular rotations in the Corn Belt is corn, wheat and red clover. As previously mentioned, difficulty has been encountered with this rotation, in part by reason of the crop sequence and in part because of the frequency with which

clover reappears in the rotation. One of the serious enemies of red clover is an anthracnose (Colletotrichum trifolii, Bain). Fortunately alsike clover and sweet clover do not serve as hosts for this parasite. The practical suggestion is made, therefore, that alsike or sweet clover be substituted for red clover every second time around the rotation where this parasite is present. Another means of control is that of lengthening the rotation to include oats or soybeans, preferably the latter because of the nitrogen-fixing capacity of its nodule organisms. Other rotation suggestions have been made in connection with the control of other parasitic organisms which live over in the soil. Economy of labor will usualy decide the sequence of crops in a rotation unless some other reason becomes more prominent. There is need to investigate rotations from the point of view of sequence and length as related to soil sanitation.

THE DISSEMINATION OF PLANT DISEASES IN MANURE

Another of the interesting suggestions of Bolley is that the manure spreader is a very effective agent for disseminating plant disease organisms. He is of the opinion that it may be desirable to compost the manure in order that the heat of fermentation may destroy these organisms. Other plant pathologists point out that diseased plant refuse should not be permitted to get into the manure heap. They question the advisability of feeding all kinds of refuse material from crops to livestock particularly where such crops as cabbage are grown. Notable examples of the almost complete loss of this and others of the more specialized crops, from parasitic organisms which have accumulated in the soil under intensive systems of cropping, are well known, particularly where little care was exercised in connection with the spread of the organisms in manure and soil.

It is evident that commercial fertilizers have certain

advantages in this connection since they are not likely to carry disease organisms. They are also especially valuable as sources of readily available mineral elements and nitrogen which, if properly balanced, are believed to aid the plant in developing resistance. There is also opportunity to control the reaction of the soil at a point which may be unfavorable for the parasitic organism but not to the host. The use of lime and sulphur in connection with the club root of cabbage and the scab of potatoes are notable examples of such methods of control.

DISEASE RESISTANT STRAINS OF PLANTS

Considerable attention is being given to the development of disease resistant strains of crop plants. A notable example of such a strain is found in the Kanred wheat which is resistant to black stem rust. In Wisconsin, Jones and his co-workers have achieved marked success with yellows-resistant cabbage. The Tennessee agricultural experiment station reports the selection of a strain of red clover which is not attacked by anthracnose. Duggar comments on this problem and mentions the iron cowpea, Dillon cotton, Scott carnation and Kieffer pear, as examples of strains or varieties of plants in which resistance to the most serious diseases commonly affecting these plants has been noted. He also adds that while disease resistance may be inherited it may change markedly as the climatic and soil conditions under which the host may be growing also change. A knowledge of the conditions of the soil as to temperature, moisture content, reaction and other properties which will best aid in the control of specific parasites is desirable. When these are known it may be possible that the system of management of the soil can be changed to satisfy the requirements without altering its effectiveness in making the mineral nutrients and nitrogen in the soil available for crop use.

STERILIZATION OF SOILS

In a small way in the greenhouse and in plant beds, control of diseases can be effected by sterilization of the soil. Formalin and steam are the two common materials used for this purpose. There is need for some method of sterilization for field purposes. The most promising material thus far suggested for this purpose is bleaching powder which liberates chlorine when in contact with the soil and leaves an alkaline residue. Kainit and common salt have also been used to some extent although the nature of their action is not definitely known. An example of a very effective organic compound is found in para-di-chlor benzene, the agent employed commonly in the destruction of peach-tree borers.

In any case it is necessary to know not only the effect of these materials on the disease organisms but also on those which are beneficial and on the crop plants as well. This makes it necessary, as a rule, that the disinfecting agent be volatile or that any residue remaining in the soil be not injurious, either directly or indirectly, in preventing the multiplication and activities of a desirable soil flora. It would seem desirable in greenhouse practice to follow soil sterilization with inoculation by the use of soil or artificial cultures known to be free of organisms capable of producing disease in the crops.

PHAGOCYTIC THEORY OF SOIL INFERTILITY

In studying the effect of temperature on oxygen absorption by soil, Russell and Hutchinson of Rothamsted found that the rate of absorption was very much increased by partial sterilization of the soil. Further study of this problem led them to believe that ordinary soils contained some factor which was inimical to the development of bacteria. They later came to the conclusion that this factor was the soil protozoa and that the abnormal bacterial

development following partial sterilization was due to the destruction of these phagocytes.

This "phagocytic theory" of soil infertility gave rise to a considerable amount of discussion and investigation on the use and effects of heat and volatile antiseptics as partial sterilizing agents in soils. As a result it has been shown that the effect of such agents is to reduce, temporarily, the total number of organisms in the soil, but that this reduction is later followed by an abnormal increase in numbers and by a marked stimulation of the plants grown on the soil. An excellent review of the investigational work on this phase of the soil problem is given by Kopeloff and Coleman, who conclude that beyond the known facts that crop growth is stimulated; that the chemical composition of the soil solution is altered and that the biological activities are profoundly influenced by partial sterilization; "data of a definite and fundamental character are wanting."

EFFECT OF VOLATILE ANTISEPTICS ON THE NUMBER OF SOIL BACTERIA

An example of the effect of partial sterilization on the number of bacteria in soils may be selected from the work of Fred. In this test carbon bisulphide was used as the antiseptic agent.

TABLE LXV

Effect of Carbon Bisulphide on Number of Bacteria in Soils

Millions of Aerobes per Gram of Soil

Time in Days	Control Soil	Treated with CS_2
1	11	1
3	22	23
5	20	25
9	14	36
13	16	90
21	19	60
25	18	68
29	15	90
60	12	58

Such a marked effect on the numbers of bacteria must be accompanied by considerable changes in the availability of the mineral elements and nitrogen in the soil. Fred found that as the numbers of bacteria increased there was an accumulation of ammonia followed later by a corresponding increase of nitrates.

INSECTS AS NEGATIVE FACTORS

Insects constitute a second group of negative biological agents whose control may make it necessary to alter the system of soil management or the cropping sequence which would otherwise be employed. The best weapon the farmer has in fighting insects is that of making conditions unnatural for them. This may be accomplished by crop rotation, by the time or depth of plowing, by the method of preparation of the soil for planting, by the time of planting and by the fertilizer practice. With the Hessian fly, rotation forces migration and subjects the frail insects to disasters enroute. Delaying the seeding of winter wheat is an effective means of control, but this requires that more fertilizer be used to enable the wheat to make sufficient growth to be able to withstand the winter weather. Cutworms, grubworms and wireworms can be controlled in part by fall, winter or early spring plowing, which subjects them to freezing. Probably one of the most difficult problems in connection with the control of insects is that presented by permanent pastures in which rotation is not feasible. Osborne calls attention to this problem in a very impressive statement in which he indicates that " run out " pastures may not be so much the result of soil exhaustion but of an accumulation of insects and other parasites of pasture grasses. It is possible that the use of phosphates and limestone, which ordinarily show such marked effects on pastures, might not be so necessary if these parasitic agents could be kept under control by some type of insecticide or fungicide.

WEEDS AS NEGATIVE FACTORS

Weeds may also be considered as parasites in the sense that they rob the crop plants of water and soil nutrients. They may also serve as hosts for diseases and insects which are injurious to crops. A notable example of this is the barberry as related to black stem rust of wheat. The control of weeds is accomplished largely through crop rotation and clean cultivation. On the continuous wheat plots at Rothamsted it has been necessary for years to hand-weed the wheat and finally to keep the plots under fallow for one crop season.

On the other hand, weeds function in the capacity of conserving agents by keeping the soil covered with vegetation and aiding in the prevention of losses by leaching and erosion. They also serve as green manuring crops. It is possible that investigation would show that certain species of plants which are now classed as weeds could be used to advantage as a means of storing up soil elements in organic combinations to be later used by crop plants. The heavy growth of ragweed (Ambrosia) white top (Erigeron), pig weed (Amaranthus) and many other common weeds would make it appear logical to study their value as green manuring crops.

BACTERIA AS COMPETITORS WITH PLANTS

In addition to the bacteria which produce diseases of plants, others which are less frequently mentioned also merit consideration. Reference has previously been made to nitrate reduction which may occur when soils are wet and as a result of which the nitrogen of nitrates may be lost as free nitrogen gas into the atmosphere. Under certain conditions bacteria may be active competitors with plants for the soil elements, particularly nitrogen. The plowing under of large amounts of straw, heavy crops of non-leguminous green manures such as rye, or fresh, strawy

animal manures often gives unsatisfactory results. A variety of reasons can be assigned for the bad effects often noted in such cases. Among these may be mentioned the fact that as the carbonaceous materials undergo decomposition the bacteria responsible for it increase more or less to the detriment of those which bring about nitrification and with the result that such nitrogen as may become available is utilized by the bacteria themselves. Frequently crops grown on soils thus treated have every appearance of lacking available nitrogen. If such materials are to be incorporated in the soil, the plowing should be done as far in advance as may be possible before the crop is planted.

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CHAPTER XX

LIMING MATERIALS

THE corrective agent employed on acid soils is usually calcium or magnesium in the oxide, hydrate or carbonate form. These products are ordinarily derived from limestones which vary in their chemical composition from almost pure calcium carbonate to nearly pure dolomite. The percentages of impurities in limestone vary within wide limits. Usually limestone is not used for agricultural purposes when the impurities exceed 15 per cent. In some localities there are large deposits of marl or chalk which are used on the soil after being pulverized. These quite often contain from 75 to 95 per cent calcium carbonate. A number of manufacturing processes have hydrated lime or carbonate of lime as a by-product which may also be used for neutralizing the acid in soils.

RELATIVE VALUES OF DIFFERENT FORMS OF LIME

A considerable amount of discussion has arisen as to the most desirable form of lime to use. Naturally interest is aroused in a product largely in proportion to the amount of advertising and sales promotion which it receives. For this reason farmers in some localities are convinced that quicklime is preferable to pulverized limestone while in other localities quite the opposite opinion prevails. Likewise there are differences of opinion concerning the relative merits of hydrated lime, marl, precipitated carbonate of lime and limestone of different degrees of fineness and with different ratios of calcium and magnesium.

It is a well-known fact that the elements calcium and magnesium have other functions in the soil and plant than simply those of neutralizing acids. It is probable, therefore, that a calcium stone or its product will be preferable to a magnesium stone or its product, in some cases, while the latter may be more effective in others. It is generally agreed, however, that the primary purpose in liming the soil is that of regulating the soil reaction and correcting certain acid soil conditions which interfere with the growth of plants. On this basis the relative merits of the several liming materials can ordinarily be ascertained from their neutralizing capacities and their solubilities. If for any reason it seems desirable to develop considerable alkalinity in the soil, which is ordinarily not the case, then there is opportunity for choice of the oxide and hydrate forms.

THE TOTAL NEUTRALIZING POWER OF LIMING MATERIALS

The relative neutralizing capacities of equal weights of limestone and its products can be determined by measuring the amount of some standard acid with which equal weights of these materials will react. Assuming that the liming materials contain no impurities, their relative neutralizing powers can be calculated from their formulæ and would be as indicated below, using calcium carbonate as the basis at a value of 100:

TABLE LXVI

RELATIVE NEUTRALIZING CAPACITIES OF LIMING MATERIALS

On Basis of Calcium Carbonate at 100

Pure Materials	Relative Weights
Calcium carbonate or limestone	100
Calcium oxide or burned lime	179
Calcium hydroxide or hydrated lime	135
Calcium-magnesium carbonate or dolomite	108
Calcium-magnesium oxide	207
Calcium-magnesium hydroxide	151

With impure materials the neutralizing power in terms of calcium carbonate must be determined for each product. Once this is known a basis is provided for calculating the relative values of the several materials, assuming uniformity with reference to their other properties. It is apparent that liming materials will vary in their rates of solution and total solubilities depending upon the chemical form in which they exist and the fineness of division of the product. MacIntire found that the solubilities in carbonated water of certain liming materials which he investigated were as indicated below:

TABLE LXVII

Solubilities of Liming Materials in Carbonated Water

In Grams of Calcium Carbonate Equivalent per Liter

Material	Grams per Liter
Calcium oxide	1.0
Magnesium oxide	18.6
Calcium carbonate	1.1
Magnesium carbonate	14.4
Limestone passing 100-mesh sieve	0.9
Dolomite passing 100-mesh sieve	0.5

Investigations of Morgan and Salter show that the rate of neutralization of soil acids by pulverized limestones of uniform fineness decreases with increasing percentages of magnesium.

FINENESS OF LIMESTONE

The effectiveness of limestone in the soil is ordinarily determined by its fineness and the extent to which the particles have been mixed with the soil. Distribution in the soil can be much more effectively accomplished if the product is relatively fine although there is a limit of fineness beyond which distribution is less easily effected in practice. White has studied the rate at which soil acidity is neutralized

as influenced by the degrees of fineness of two limestone products. A comparison was also made with burned lime as indicated below:

TABLE LXVIII

FINENESS OF LIMESTONE AS RELATED TO EFFECTIVENESS IN ACID SOILS

Per Cent of Lime-Absorbing Capacity of Soil Satisfied in Four Weeks

Product Used	From Limestone	From Dolomite
Burned lime	90	84
100-mesh limestone	80	78
60-mesh limestone	61	29
20-mesh limestone	33	10
8-mesh limestone	22	7

Ground limestone usually contains a mixture of fine and coarse materials and is therefore somewhat more effective than would be indicated by the figures for the coarse product in the table. Here again the dolomitic stone was slow in its rate of action, not only in the case of the pulverized rock but also in that of its burned product, although the differences were much less marked in the fine materials than in the coarser products.

COMPARISON OF HYDRATED LIME AND LIMESTONE

Hartwell and Damon have reported a comparative test of hydrated lime and pulverized limestone derived from the same dolomitic rock. The limestone was pulverized to the extent that all of it would pass a 10-mesh sieve, with 56 per cent passing a sieve with 80 meshes to the inch. Some of the finer material was separated from this product for further comparison. The test extended over a five-year period The crops grown were alfalfa, beets, carrots and barley. A liberal application of fertilizer was made in order, if possible, to prevent the lime from having any other

effect than that of correcting acid soil conditions. The liming materials were applied in amounts equivalent to 2140 pounds of calcium carbonate per acre at the beginning of the test. The following data show the immediate and average effects of the liming materials on the crop yields:

TABLE LXXIX

COMPARISON OF HYDRATED LIME AND GROUND LIMESTONE

Yield of Crops in Bushels or Hundredweight per Acre

	Hydrated Lime	10-Mesh Limestone	80-Mesh Limestone
First-Year:			
Alfalfa	35.4	27.1	37.8
Carrots	219.0	172.0	227.0
Beets	280.0	215.0	299.0
Barley hay	11.2	7.6	6.2
Five-Year Averages:			
Alfalfa	41.8	36.1	32.6
Carrots	338.0	311.0	362.0
Beets	243.0	226.0	227.0
Barley hay	25.1	25.1	23.1

The five-year average yields of the unlimed plots were 21.8 hundredweight of alfalfa, 278 bushels of carrots, 92 bushels of beets and 19.4 hundredweight of barley hay per acre. The authors conclude that hydrated lime is more effective the first year but that for the five-year period the 10-mesh product is practically equal in its effect to an equivalent amount of neutralizing power in the form of hydrated lime.

TIME OF APPLICATION OF LIMESTONE

When limestone is added to the soil, its effectiveness is determined in large part by the extent to which it can be distributed and thoroughly mixed with the soil. It is for

this reason that it is usually recommended that liming materials be added to the soil immediately following plowing in order that the two may be thoroughly mixed in the preparation of the seed bed and perhaps in the subsequent cultivation of a clean culture crop such as corn. Under conditions in which corn is to be followed by one or more other crops, which, like it, are not especially sensitive to acid soil conditions, the soil and limestone may become very intimately mixed by the time the legume crop, from which the maximum benefit is to be derived, appears in the rotation. Under such conditions a somewhat coarser product might be used to advantage.

SUMMER AND WINTER APPLICATIONS OF LIMESTONE

In general farming where large acreages of land are under cultivation, spring and fall applications of limestone on corn and wheat, respectively, or on similar crops in other rotations, are attended with considerable difficulty because of the limited amount of time available. Oftentimes with already delayed planting by reason of irregularities of the weather, a further delay for the purpose of liming the soil may result in considerable reduction in yield of the crop grown that year. In general the net effect of such difficulties is to prevent the regular use of limestone in adequate amounts. It is for this reason that it has been found desirable to consider the means by which limestone could be made effective when applied at some other season of the year. The most convenient times, from the point of view of the farmer of the Central West, are in the summer and winter rather than in the spring and fall. With a rotation of corn, wheat and clover, the limestone may be applied in the winter as a top dressing on wheat and preceding the sowing of clover seed; in the summer on the young clover following wheat harvest; in the succeeding winter on the young clover; or during the next summer on the clover sod after the hay crop has been harvested.

It is apparent that maximum efficiency for that particular season can scarcely be expected when the limestone is applied to the surface and enters the soil only as it may be carried downward in solution in the soil water. This concentration of the limestone on the surface may be favorable to the new seeding of clover, however, since the soil at the surface would have a greater alkalinity than if the limestone were equally distributed through a cultivated layer of soil. It is possible if the young clover plants get

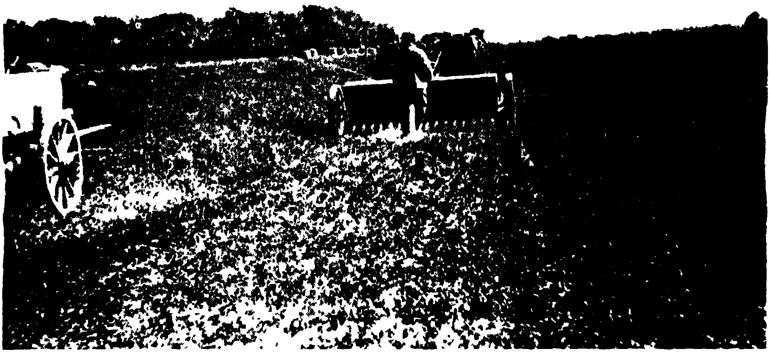


FIG. 21.—"By applying the limestone on the clover sod in August the work can be done when the roads are in good condition and while the work on the farm is slack."

well started, that they may be able to satisfy their lime requirements from the surface soil even while their roots are growing downward in an acid sub-surface soil. The more soluble burned or hydrated lime or the very finely pulverized limestone should be more effective under such conditions.

APPLICATION OF LIMESTONE TO CLOVER SOD

When limestone is applied on the clover sod previous to plowing for corn, the question arises as to the distribution of this limestone when the soil is plowed. Usually

the furrow is set on edge instead of being turned completely over. The limestone would then be left in vertical layers and subsequently mixed with the soil by the horizontal action of cultivating machinery. The efficiency of such a method of distribution is somewhat discounted by the fact that usually only the surface few inches of soil are thoroughly mixed in the preparation of the seed bed, and also because the jointer tends to bury the limestone more deeply than would be the case if it were not used. Over a period of years in which the furrow is turned several times, the limestone probably becomes well mixed with the soil, particularly if the furrow slice is deepened a little each year. Where the use of limestone is made a regular part of the scheme of soil management the plan should prove satisfactory, both from the point of view of the distribution of labor and the efficiency of the limestone.

This assumption is supported by some experimental evidence on the subject secured at the Ohio Agricultural Experiment Station. In these tests two tons of finely pulverized limestone per acre were applied once during each four-year rotation but at different times in the rotation on the various plots in the test. The data of crop yields for the first eight years of the test are given below:

TABLE LXX

Effectiveness of Limestone as Determined by Time of Application

Increase from Two Tons of Limestone—Wooster Silt Loam Soil

Time of Application of Limestone	Corn, Bu	Oats, Bu	Wheat, Bu	Clover, Cwt.
On corn	10.22	1.65	2.15	10.42
On wheat	8.09	0.16	2.80	11.78
On new seeding clover	7.31	0.24	2.41	7.45
On clover sod	9.97	1.73	3.53	7.36
One-fourth on each crop	6.76	1.43	1.77	8.49

Discussing these tests, Williams writes that it is fortunate that the most convenient time of application is so satisfactory in its results. By applying the limestone on the clover sod in August the work can be done when the roads are in good condition and while the work on the farm is slack.

In the more intensive systems of market garden farming there is reason to believe that more attention should be given to regulating the reaction of the soil solution to suit the needs of each crop grown. Mention has been made of the use of sulphur as an agent to develop acidity for preventing the attacks of potato scab. The use of burned lime for producing a high alkalinity for cabbage as a means of preventing the development of club root has also been suggested. Further investigation will undoubtedly show the *p*H which will most nearly fit the requirements of each crop or will best hold in check its parasites. In intensive farming, therefore, it is to be expected that the burned products may be in many ways more useful than the ground limestone. The application can be timed to fit the needs of each crop grown.

SOME POINTS OF CONTROVERSY

An excellent digest of the many controversial points in connection with the use of limestone and its products is given by Frear. A further review and supplemental study of the effect of caustic lime on the soil is given by MacIntire. The data available indicate that there is little choice among the several chemical forms of lime, in the quantities in which they are ordinarily used in general farming, which can be supported by adequate experimental evidence. Usually the deciding point is the cost per unit of effective neutralizing power delivered and applied to the soil. This means that those general farmers who are near the railway station or source of supply will be more interested in the coarser and therefore cheaper materials such as limestone

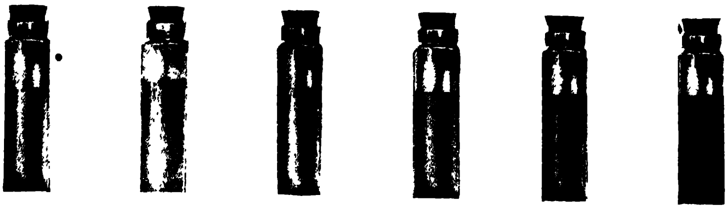
screenings. Longer hauls make it advisable to use smaller amounts of more finely pulverized limestone. Where the hauling distance is still greater, burned lime may be the most economical product. The hydrated lime is of necessity more expensive per unit of effective neutralizing power, but finds a place on those farms where immediate effects, a well-developed alkalinity and convenience in handling command a premium. Dolomitic stone and its products have higher neutralizing powers than calcium stone and its products, but the lower solubility of the former and its slower rate of action in the coarser limestone products may more than overbalance this advantage.

SUGGESTED USE OF LIMESTONE

The amount of any given liming material to use will depend largely upon the acid condition of the soil, the crop or crops to be grown and the economic problems involved. Several of the agronomists have given rather specific suggestions on the amount of lime or limestone to use, in which an attempt was made to take all three of these variables into consideration. One of the most serious difficulties involved is that of determining how much lime is required by the soil to bring its reaction to various points believed to be the optima for the several crops. A number of methods have been suggested for determining the capacity of the soil to absorb lime among which that of Veitch, previously mentioned, was formerly rather generally employed for quantitative purposes. A somewhat more convenient method, and one which is perhaps equally satisfactory as a means of determining the relative amounts of lime required by soils to bring them to some desired reaction, is that of extracting the soils with a solution of some soluble neutral salt, such as potassium nitrate or calcium acetate, by which the amount of replaceable iron and aluminium can be estimated. Of these the Hopkins and the Jones methods are in common use.

SUGGESTED USE OF LIMESTONE

Department of Soils—The Ohio State University



1 2 3 4 5 6

Fig. 22.—Color Chart for Thiocyanate Soil Acidity Test

Crops	Soils	Limestone Needed in Tons per Acre					
		1	2	3	4	5	6*
Sweet clover, alfalfa, sugar beets, cabbage, lettuce, onions, spinach, garden peas, cauliflower	Good	None	None	1	2	3	4
	Poor	None	1	2	3	4	6
Red clover, mammoth clover, barley, carrots, rape, turnips, radishes.	Good	None	None	½	1	2	3
	Poor	None	½	1	2	3	4
Alsike clover, soy beans, vetch, corn, timothy, bluegrass	Good	None	None	None	½	1	2
	Poor	None	None	½	1	2	3
Japan clover, wheat, buckwheat, oats, potatoes, rye, strawberries	Good	None	None	None	None	1	2
	Poor	None	None	None	½	2	3

* These numbers refer to the depth of color as indicated on the chart above

Most of these methods are of use only in the laboratory. Accordingly, considerable attention has been given to the methods which might be more useful for field purposes. Of

these the Comber acid soil test is the most promising. In this test from 2 to 3 grams of soil are shaken with 5 cubic centimeters of a 5 per cent solution of potassium thiocyanate, dissolved in alcohol, which gives a red color with acid soils, the depth of color being determined by the amount of replaceable iron in the soil. Since most soils contain iron which can be thus extracted when these soils become acid, the test seems to give a roughly quantitative answer to the question of how much lime to apply, if the variation in the requirements of crops and the economic factors are taken into consideration.

As an example of the suggestions on the use of liming materials which have been made by the various agronomists, may be mentioned those distributed among the farmers of Ohio by the Department of Soils of the Ohio State University. The color chart (Fig. 22) shows the depths of red produced by shaking soils of different degrees of acidity with a solution of potassium thiocyanate. The succeeding table gives the suggested rate of application of limestone for the several crops when grown on soils of various degrees of acidity as indicated by the test:

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CHAPTER XXI

NITROGEN FERTILIZERS

It is generally assumed that a large part of the nitrogen of crops will be secured from atmospheric sources by the growth of legumes and through the agency of non-symbiotic nitrogen-fixing organisms. A combination of circumstances has made it somewhat more difficult to realize a profit from the use of commercial nitrogen than from either of the other fertilizer elements ordinarily applied. This is particularly true with such crops as corn and wheat and under conditions in which the element nitrogen costs from two to three times as much as either phosphorus or potassium. It is possible that improved processes in nitrogen fixation will reduce the cost of this element, in which case there is reason to believe that it can be used somewhat more liberally to advantage.

NITROGEN ECONOMY IN GENERAL FARMING

In the livestock system of farming, in which the crops produced on the farm are fed and the manure is returned without loss to the field, there may be little need for commercial nitrogen. In the grain system of farming it is usually recommended that the legume crops as well as the stalks, straw and other crop residues be plowed under. Yet it is rather generally true that soils, which have been farmed for a period of twenty-five years or more under either system as ordinarily practiced, are deficient in nitrogen, and its application in available forms can be expected to produce considerable increases in yield. The use of commercial nitrogen on general farms under present con-

ditions must be considered largely in the nature of an emergency measure by which the productive capacity of the soil may be more rapidly increased, after which the livestock system of farming may be put into effect and the further use of commercial nitrogen may no longer be profitable. On the other hand there is no legitimate argument against the supplemental use of commercial nitrogen in general farming if by so doing larger yields can be produced at an increased acre profit.

NITROGEN ECONOMY IN INTENSIVE CROPPING SYSTEMS

As long as manure was abundant and cheap the specialized crop farmer made use of it in large amounts, not only as a source of nitrogen, but also for the reason that when applied in liberal quantities it served to improve the physical properties of the soil. With the advent of the automobile and an ever-enlarging acreage of market garden and canning crops, it has been found necessary to supplement such manure, as is available, with more green-manures and commercial fertilizer. In some cases the green-manure-fertilizer system of soil management has been entirely substituted for the phosphated manure program. The cost of fertilizer being only a relatively small part of the total acre cost of growing specialized crops, nitrogen and other elements may be supplied in much larger amounts than they are removed in the crops. Earliness and quality command a premium on the market sufficient to justify the expense. In such cases the excess nitrates may be lost in considerable amounts in the drainage water, particularly in the ordinary sandy loam soils on which truck crops are most frequently grown.

SOURCES OF COMMERCIAL NITROGEN

Fertilizer nitrogen is derived from a variety of sources. Some of these are the chief products of some manufacturing or mining process. Others are by-products of some

industry. According to Waggaman the amounts and sources of nitrogen produced in North American industries in 1918 were as follows:

TABLE LXXI

COMBINED NITROGEN PRODUCED IN AMERICAN INDUSTRIES (1918)

Name of Industry	Material Produced	Tons Material	Per Cent Nitrogen
Cyanamid	Fixed nitrogen	64,000	25
Packing plants	Tankage (high grade)	211,329	8 9
	Tankage (low grade)	59,604	4 5
	Dried blood	35,163	12
	Hair	8,754	12–15
	Hoofs and bone	1,671	10–15
	Meat scrap	3,233	8 8 5
	Raw bones	33,611	2 5
	Dried bones	21,475	1 5
Fish industry	Fish scrap	53,028	5 8
Cottonseed mills	Cottonseed meal	1,616,617	6 5
Coke ovens	Ammonium sulphate	348,651	20
Municipal gas works	Ammonium sulphate	28,450	20
Tobacco industry	Tobacco stems	37,200	3 5 1
Peat industry	Organic nitrogen	79,573	2-3
Wool industry	Organic nitrogen	1,002	7

It is also known that considerable amounts of garbage tankage, leather scraps and a great variety of organic waste products containing nitrogen, and not included in the above list, find their way into the fertilizer factory. Of those mentioned only a part of the tonnages were used for fertilizer purposes. This is especially true of such products as high-grade tankage and cottonseed meal which command a higher price as feeding stuffs than as fertilizers.

During the year 1918 the United States also imported 1,869,850 tons of nitrate of soda from Chile. Smaller amounts of sulphate of ammonia, nitrate of lime, guano and other carriers of nitrogen were imported from other countries. It is difficult to estimate the total amount of nitrogen

used in fertilizers. However, the above table gives some idea of the variety of materials which can be used for this purpose and the relative amounts available.

SYNTHETIC NITROGEN

The greater part of the nitrogen in fertilizers must come, in the future, from Chilean nitrate, coke oven sulphate of ammonia or from such materials as are synthesized from atmospheric nitrogen. The four compounds so far produced in the fixation processes are cyanamid, sulphate of ammonia, ammonium nitrate and nitrate of lime. Some idea of the possibilities of development of the nitrogen-fixation industry may be gained from the study of the following table from the American Fertilizer Handbook, showing the estimated World's capacity of air nitrogen for 1920:

TABLE LXXII

ESTIMATED WORLD CAPACITY OF AIR NITROGEN PLANTS (1920)

Country	Tons Nitrogen *
Germany	393,000
France	11,000
Italy	13,000
Scandinavia	58,000
Austria	22,000
Switzerland	7,500
Japan	12,000
Canada	12,000
United States	40,000
Total	598,500

* Metric tons.

RELATIVE VALUES OF VARIOUS CARRIERS OF NITROGEN

The availability of the nitrogen in fertilizers other than nitrates is largely determined by the rate at which the nitrifying organisms are able to change it to the nitrate form.

The normal bacterial action on proteins results in the formation of ammonia, nitrites and nitrates. As previously mentioned, it has been shown that while forms of nitrogen other than nitrates are apparently used by some crops, ordinarily the nitrates are the most effective.

A considerable number of comparative trials of the various carriers of nitrogen have been made by soil investigators. Of these may be mentioned those conducted at the Ohio Agricultural Experiment Station under the direction of Thorne as being somewhat typical. In these tests the various materials have been compared when used in addition to limestone, acid phosphate and muriate of potash. The nitrogen carriers were applied in such amounts as to provide equal quantities of nitrogen. The crops grown in rotation were corn, oats, wheat, clover and timothy, the fertilizer being divided among the first three crops mentioned. The data cover the period from 1900 to 1918.

TABLE LXXIII

COMPARATIVE EFFECTIVENESS OF VARIOUS CARRIERS OF NITROGEN SOIL LIMED AND TREATED WITH CARRIERS OF PHOSPHORUS AND POTASSIUM

Increase from Nitrogen Carriers Calculated on Basis of Nitrate of Soda at 100

Carrier of Nitrogen	Corn	Oats	Wheat	Clover	Timothy
Nitrate of soda	100	100	100	100	100
Oil meal . . .	69	61	13	27	31
Dried blood . .	61	14	49	11	19
Sulphate of ammonia	70	53	80	69	55

The nitrate of soda was most effective and the organic carriers least effective as would be expected from previous considerations of the bacterial processes which must take place before the latter forms of nitrogen can be used by crops. Experiments conducted by other investigators have indicated that perhaps the relative effectiveness of these

materials may be represented approximately by 100, 90 and 80 for nitrate of soda, sulphate of ammonia and dried blood, respectively, with somewhat lower figures for the other less readily decomposable organic materials.

More recently comparative trials have been begun with nitrate of lime and calcium cyanamid. The former should be as useful a carrier of nitrogen as nitrate of soda except that this will depend somewhat upon the relative values of the sodium and calcium ions when applied to the soil. In the case of cyanamid there is reason to believe that its nitrogen has an availability somewhat similar to that in sulphate of ammonia, although in this case again there is a complication in the fact that cyanamid not only contains calcium in combination with the nitrogen, but, in addition, from 25 to 30 per cent of hydrated lime. Cyanamid is toxic to plants unless applied several days before the crop is planted.

PROCESSED ORGANIC NITROGEN

A considerable number of the organic carriers of nitrogen do not yield readily to the processes of decomposition in the soil. It is for this reason that many states require by law that the manufacturer have printed on the fertilizer bag, or on the tag attached thereto, the source or sources of the nitrogen contained in the fertilizer. Among the more slowly available materials may be mentioned garbage tankage, hair, leather and wool waste and peat. In the modern fertilizer plant such organic materials are subjected to what is known as the "wet mixing process" in which sulphuric acid is added to the mixture of phosphate rock and organic materials and both the nitrogen and phosphorus are made soluble in the process.

Hartwell and Pember studied the effectiveness of the nitrogen of a few of the organic ammoniates before and after acidulation, in comparison with that of dried blood. The crops grown were Japanese millet, oats and buckwheat.

FIG. 23.—"The cost of fertilizer being only a relatively small part of the total acre cost of growing specialized crops, nitrogen and other elements may be supplied in much larger amounts than they are removed in these crops"

The following table shows the relative increases in yield resulting from the use of these materials in comparison with dried blood, the nitrogen of which was assumed to have an availability of 80 as compared to 100 for that in the form of nitrate of soda:

TABLE LXXIV

EFFECT OF PROCESSING ON AVAILABILITY OF ORGANIC NITROGEN. RELATIVE YIELDS OF MILLET, OATS AND BUCKWHEAT

In Comparison with Dried Blood at 80

Material	Non-acidulated	Acidulated
Hair	33	64
Leather	23	80
Garbage tankage	13	8
Mixture of above three	49	84

The data indicate that processed nitrogen has an availability approximately equal to that of dried blood. No explanation is given of the low figure shown for acidulated garbage tankage.

AVAILABILITY TESTS FOR FERTILIZER NITROGEN

It is to be expected that low-analysis mixed fertilizers will carry a considerable part or all of their nitrogen in these insoluble and slowly available forms. It is necessary, therefore, to have some laboratory means of determining the quality of the organic nitrogen in fertilizers. Biological methods, in which the amount of ammonia or nitrates produced under standard conditions are determined, have been suggested. Such methods unfortunately are not well suited to ordinary laboratory routine. The method adopted as official by the Association of Official Agricultural Chemists is one known as the "permanganate method" in which the water insoluble residue of a sample of the fertilizer is digested in neutral or alkaline permanganate solution under certain standard conditions, after which the amount of nitrogen remaining in the undissolved residue is determined. The choice between the neutral and the alkaline solution depends on the nature of the organic material. The method is an empirical one and in many ways not satisfactory, but intelligently applied it can be depended on to give a fairly reliable clue to the usefulness of the nitrogen in the fertilizer. From this test the control chemist can determine whether or not the nitrogen should be "passed."

MIXTURES OF NITROGEN CARRIERS IN FERTILIZERS

Since nitrate of soda is immediately available for crop use, once it is applied to the soil, and since if it is not used by the crop it may be carried off by the drainage water, particularly in sandy soils, it has been commonly held that

a mixture of carriers of nitrogen is to be preferred to any one of them when used alone. By the use of such mixtures it is assumed that it is possible to have the nitrogen become available at a rate which will satisfy the needs of the growing crop throughout the season.

The experimental data on this subject are not entirely satisfactory, but indicate that there is little basis for such a belief, particularly when the amount of nitrogen applied is no greater than is customarily added in ordinary field practice. Thus at the North Carolina Agricultural Experiment Station in an eight-year test on corn, mixtures of nitrate of soda and dried blood were compared on Cecil sandy clay loam soil with each of these materials when applied alone with the following results:

TABLE LXXV

COMPARISON OF MIXTURES WITH INDIVIDUAL CARRIERS OF NITROGEN. 8-YEAR AVERAGE ACRE INCREASES OF CORN—CECIL SANDY CLAY LOAM

9 Pounds of Nitrogen per Acre Used with Carriers of Phosphorus and Potassium

Nitrogen Applied		Corn, Bu.	Stover, Cwt.
Planting Time	July 1		
Blood $\frac{5}{6}$, nitrate $\frac{1}{6}$.	None . .	9.45	7.85
Blood $\frac{1}{2}$.	Nitrate of soda $\frac{1}{2}$	9.05	6.65
Nitrate of soda $\frac{1}{2}$.	Nitrate of soda $\frac{1}{2}$. .	10.80	7.15
Blood $\frac{1}{2}$.	Blood $\frac{1}{2}$ . .	8.85	6.35

The nitrogen of nitrate of soda was more effective than that of dried blood. Nothing seemed to be gained by mixing the two. When larger amounts of nitrogen are used it is possible that mixtures containing nitrogen from several sources will be more effective than nitrate of soda alone. Thus Blair reports a five-year average acre yield of potatoes

of 251 bushels when 1600 pounds of a 4-8-3 fertilizer containing all of its nitrogen as nitrate was applied, as compared to 253 bushels with a mixture of nitrate of soda and sulphate of ammonia, and 257 bushels when fish or tankage was substituted for the latter. The soil in this test was a heavy loam. On sandy soils the differences might be more marked. The evidence indicates that sulphate of ammonia and organic carriers of nitrogen, when used, should be mixed with nitrate of soda rather than used alone.

SOME INDIRECT EFFECTS OF NITROGEN CARRIERS

Mention has been made of the fact that calcium and sodium nitrates, while carrying their nitrogen as nitrates, may not produce the same results by reason of the fact that the calcium and sodium ions are known to have beneficial effects as such. Similarly cyanamid and sulphate of ammonia contain elements other than nitrogen which may influence the growth of crops. There is a further complication in that substances like nitrate of soda are physiologically alkaline while sulphate of ammonia is acid. Some notable examples of injury from the long-continued use of sulphate of ammonia on unlimed soils have been recorded, notably at the Woburn Experimental Farm in England, at the Pennsylvania Agricultural Experiment Station and at the Rhode Island Agricultural Experiment Station. On the other hand, sulphate of ammonia carries the element sulphur which is of especial importance as a fertilizer on certain crops high in this element and on soils deficient in it. The problem is somewhat complicated and the effectiveness of any carrier will depend upon a variety of factors of which the need of the crop for nitrogen as nitrate is only one.

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CHAPTER XXII

PHOSPHORUS FERTILIZERS

THE content of phosphorus in soils is relatively low in comparison with nitrogen, potassium and the other soil elements essential to plant growth. The average soil of the Middle West will contain about three times as much nitrogen and about thirty times as much potassium as it does of phosphorus. There is no atmospheric supply of phosphorus on which plants can draw, as is possible in the case of nitrogen. The element can be returned to the soil in the form of manure, but some supplemental source of phosphorus is essential to replace that removed from the soil in crops or in the bone and other products of animals to which the crops are fed. Fortunately, there is little loss of this element in the drainage water, since soils have a somewhat remarkable absorbing capacity for phosphates. As a rule, however, after the soil has been under cultivation for a period of twenty-five years or more, the crops grown on it will respond very markedly to applications of phosphatic fertilizers. This statement is so nearly universally true that deposits of phosphate rock are looked upon as one of the most important natural resources of any nation. The necessity for the conservation of phosphate deposits is well presented by Van Hise.

SOURCES OF PHOSPHATE FERTILIZERS

By far the most important source of phosphorus is that of phosphate rock which is found in large deposits in various parts of the world. The United States of America has the most extensive of these rock deposits now known to exist.

Phosphate rock is found in large amounts in Florida, Tennessee, the Carolinas and in Utah, Wyoming, Idaho and Montana. While the rock can be used as such when finely pulverized, it has found its largest use in the form of acid phosphate, a product resulting from the action of sulphuric acid on the phosphate rock.

Phosphates are also produced as by-products in the packing and steel industries in the form of bone meal and

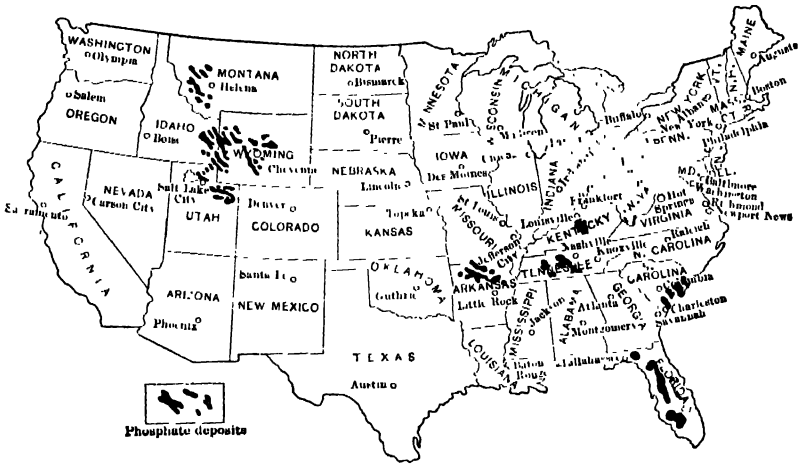


FIG. 24.—"Deposits of phosphate rock are looked upon as one of the most important natural resources of any nation."

basic slag, respectively. A considerable portion of the phosphorus removed from the soil is thus returned to it, but as the population increases a larger percentage of the total phosphorus content of plants is tied up in the bones of human beings of which little is recovered to the cropped soil. The mineral phosphates and bone contain their phosphorus in the form of tri-calcium phosphate. Basic slag is found to have an excess of calcium oxide and some silica in the phosphate molecule, the exact formula of the compound being unknown. In addition basic slag, being a product of the blast furnace, contains some free calcium

oxide and is found to have a value for neutralizing soil acids of approximately half that of an equal weight of limestone. Bone meal and basic slag are ordinarily ground to a fine powder in preparation for use on the soil. Frequently, the fat is first removed from the bone by steaming or extracting with some solvent.

THE PHOSPHATE ROCK INDUSTRY

Some idea of the size of the phosphate rock industry in the United States may be gained from the following data, which give the quantities marketed and exported for the period 1913 to 1918 as reported in the American Fertilizer Hand Book for 1920:

TABLE LXXVI

PHOSPHATE ROCK PRODUCTION IN THE UNITED STATES

Year	Marketed, Long Tons	Exported, Long Tons	Exported, Per Cent
1913	3,111,221	1,366,508	44
1914	2,734,034	964,114	35
1915	1,835,667	253,421	14
1916	1,982,385	243,678	12
1917	2,584,287	166,003	6
1918	2,490,760	143,155	6

The exportation of phosphate rock was very much curtailed during the World War, but there was an increased domestic demand for it in the form of acid phosphate, so that the total yearly production had almost returned to the pre-war level when the armistice was signed. Most of this phosphate rock is secured from the Southern States, the Western deposits being too far removed from the market to be profitably worked. More recently a Montana mining company, which has sulphuric acid as a by-product, has begun the manufacture of acid phosphate containing approx-

imately 45 per cent of phosphoric anhydride, a product almost three times as concentrated in phosphorus as the ordinary acid phosphate. By reducing the weight per unit of phosphorus, it has been possible to market some of this material in the Central West in competition with acid phosphate from Tennessee and Florida.

THE MANUFACTURE OF ACID PHOSPHATE

In the manufacture of acid phosphate, the ground phosphate rock is treated with approximately an equal weight of sulphuric acid. The resulting product, after curing and subsequent pulverization, constitutes the ordinary 14 to 20 per cent acid phosphate of the fertilizer trade, the percentage depending upon the purity of the original rock. The action of the sulphuric acid results in the formation of calcium sulphate, with the consequent loss of the calcium from the phosphate molecule. The resulting product, commonly known as acid phosphate, is a mixture of calcium sulphate and the mono-, di- and tri-calcium phosphates. A 16 per cent acid phosphate is one in which the phosphoric anhydride in the mono- and di-calcium phosphate forms amounts to 16 per cent by weight of the product. The mono-calcium phosphate is soluble in water, the di-calcium phosphate will dissolve in weak acids, while the tri-calcium phosphate, which escaped the action of the sulphuric acid, must be treated with strong acids in order to effect its rapid solution.

THE PRODUCTION OF CONCENTRATED ACID PHOSPHATES

As a means of economizing in freight and also for the more economical utilization of low-grade phosphate rock, it has been found desirable to produce what are known as "treble-superphosphates" containing higher percentages of phosphorus. Mention has been made of the 45 per cent acid phosphate produced in Montana. This product is made by treating phosphate rock with an excess of sulphuric

acid after which the resulting phosphoric acid is used to treat an additional quantity of phosphate rock. As a result of this process the calcium sulphate, which ordinarily dilutes the acid phosphate about 50 per cent, is eliminated and a highly concentrated product produced.

With the lower grade phosphate rock it may be preferable to drive off the phosphoric anhydride by heat and collect it in water, after which the resulting phosphoric acid can be used to produce concentrated acid phosphate from high-grade phosphate rock. Considerable attention is being given to this process by the United States Department of Agriculture.

The higher percentage acid phosphates are often built up from the ordinary 16 or 18 per cent to 20, or more, by mixing with them a given amount of a more concentrated product. The demand is largely for the 16 per cent acid phosphate, but undoubtedly the amount of the higher percentages used will increase when the supply of "treble superphosphate" permits of advertising the advantages of the more concentrated products.

AVAILABILITY TESTS FOR PHOSPHORUS

Since only the mono- and di-calcium phosphates are products resulting from the action of sulphuric acid on the phosphate rock, it is necessary to have some means of determining what part of the total phosphorus still remains in the unchanged tri-calcium form. The method of determining the amount of phosphorus in the mono- and di-calcium forms, which is ordinarily spoken of as "available," has been adopted as official by the Association of Official Agricultural Chemists. This method calls for digesting the washed sample of acid phosphate with a neutral solution of ammonium citrate for a period of thirty minutes at a temperature of 65° C. The phosphate remaining undissolved after this treatment is termed "insoluble" or "unavailable." The method is an arbitrary one, but has

become generally adopted and is found to meet the requirements of an availability test fairly satisfactorily.

COMPARATIVE VALUES OF ACID PHOSPHATE AND PHOSPHATE ROCK

Although acid phosphate has become popular as a carrier of phosphorus there has been and still continues to be a considerable amount of discussion as to the relative value of finely pulverized phosphate rock and acid phosphate. The most prominent advocate of the use of phosphate rock was the late Cyril G. Hopkins, whose arguments in favor of its use were given wide publicity. A comprehensive review of the experimental evidence on phosphate rock in Illinois and at the several other agricultural experimental stations in America and Europe is given by Waggaman and Wagner. In general it may be said that these data indicate that the untreated rock is quite effective under certain conditions and that the choice between it and acid phosphate is largely determined by the system of cropping and of soil management which the individual farmer may adopt. For the most part acid phosphate is used in intensive systems of farming, while phosphate rock finds a prominent place in the more extensive systems of farming practiced in the Corn Belt.

Probably the most important and significant comparative test of the two is that which has been under way at the Ohio Experiment Station at Wooster for the last twenty-one years. In this test acid phosphate and phosphate rock were applied with manure on the clover sod, which was plowed for corn in rotation with wheat and clover. The manure was used at the rate of 8 tons per acre, 40 pounds of acid phosphate or phosphate rock being scattered over each ton before it was hauled to the field. In reviewing the following comparative data it is well to have in mind that acid phosphate contains, in addition to the several calcium phosphates, about 50 per cent by weight of calcium

sulphate which has long been known to be of considerable value in stimulating crop growth. Further, under the conditions of the test, twice as much phosphorus was supplied in the phosphate rock as was contained in the acid phosphate and at a cost of something over one-half of that of the latter.

TABLE LXXVII

COMPARATIVE EFFECTS OF PHOSPHATE ROCK AND ACID PHOSPHATE

320 Pounds of Phosphate—8 Tons Manure—Limed Wooster Silt Loam Soil

Carrier of Phosphorus	21-Year Average Acre Increases in Yields from Use of Manure Alone or Treated as Indicated		
	Corn, Bu.	Wheat, Bu	Clover, Cwt
Acid phosphate	33 0	15 3	21 4
Phosphate rock	27 9	12 7	17 3
Gypsum—No phosphate	25 6	10 8	10 4
Manure alone	21 2	9 8	11 0
Unmanured yields	35 7	13 7	28 1

It will be noted that the gypsum increased the effectiveness of the manure on the corn and wheat. A number of other problems involved merit consideration among which may be mentioned the fact that the rate of accumulation of phosphorus in the soil is greater from the use of phosphate rock than from acid phosphate, although to date, there is no evidence that this residue is of any added value.

PHOSPHATE ROCK—SULPHUR—SOIL COMPOSTS

A study of the activities of sulphur oxidizing organisms in soils led Lipman to suggest the use of elemental sulphur in connection with phosphate rock. Preliminary studies had shown that sulphur was readily oxidized in soils and it

seemed reasonable to believe that if a sulphur-soil-phosphate rock compost was prepared the acidulating action of the sulphuric acid could be concentrated largely on the phosphate rock. Further extended investigation by Lipman and his associates showed that the rate of oxidation of sulphur can be considerably increased by inoculating it with active strains of sulphofying organisms.

The Lipman process of mixing rock phosphate, inoculated sulphur and soil in the ratios of two of the first to one of each of the others has proven successful. The extent to which this method of securing available phosphoric acid will be used in practice is problematical. A critical review of the literature on this subject together with an extended bibliography is given by McLean.

CAPACITIES OF PLANTS TO UTILIZE PHOSPHATE ROCK

Truog believes that plants which have a relatively high content of calcium also have a relatively high capacity to secure phosphorus from phosphate rock. He explains this assumption on the basis that if the calcium acid carbonate produced by the action of carbonic acid on phosphate rock is removed by the crop the reaction can proceed. Bauer tested this assumption further in a comparison between the growth increase resulting from the use of acid phosphate and phosphate rock. In this test the phosphate rock was applied at a rate corresponding to that ordinarily employed in Illinois field practice.

The calcium content of the tops of the plants and their capacity to utilize phosphate rock are not always correlated. Bauer explains these discrepancies on the basis of the differences in the character of their root systems. Plants having an extensive development of fibrous roots are able to secure a larger amount of phosphorus from phosphate rock by reason of their coming in contact with more of it in the soil and by taking up more of it as it passes into solution. Whatever the explanation, the fact remains

TABLE LXXVIII

RELATIVE CAPACITIES OF PLANTS TO UTILIZE PHOSPHATE ROCK

By Comparison with Normal Growth Produced by the Use of Acid Phosphate

Plant	Calcium in Tops, Per Cent	Percentage of Normal Growth
Red clover	1 01	33
Wheat	.	34
Oats		41
Corn	0 57	41
Timothy	0 36	45
Soybeans	1 38	47
Rape	1 59	54
Alfalfa	1 15	62
Rye	.	66
Buckwheat		72
Red top	0 63	72
Red sorrel	0 94	82
Sweet clover	1 37	83

that the several plants vary in their relative capacities to use phosphate rock in the quantities in which it is ordinarily supplied. The choice between acid phosphate and phosphate rock will therefore be determined in part by the crops to be grown. If, for example, sweet clover is to be used as a green manuring crop it would seem probable that phosphate rock could be used to advantage in preparation for the growth of the crop.

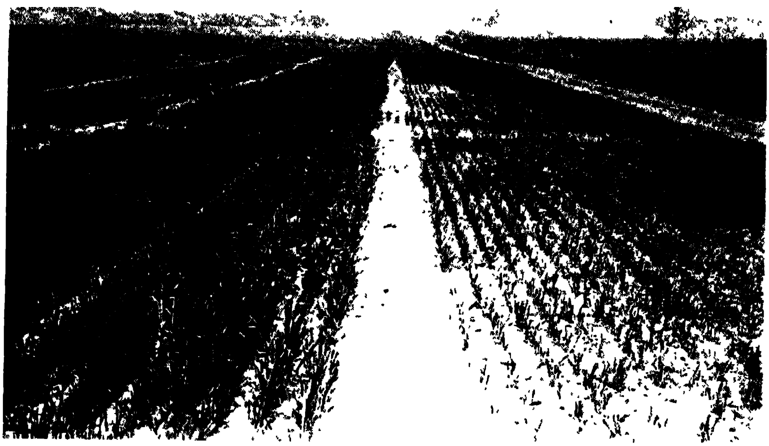
PHOSPHATE ROCK ON ACID SOILS

Assuming that Truog's hypothesis is correct, it would be expected that phosphate rock could be used to best advantage on acid soils which yielded up very little calcium to the soil solution. Such seems to be the case. Several experiment stations, notably Indiana and Kentucky, have reported data which indicate that phosphate rock is relatively more effective in comparison with acid phosphate

on acid soils when no supplemental liming treatments are given the soils.

COMPARISON OF ACID PHOSPHATE, BASIC SLAG AND BONE MEAL

While the greater part of the phosphorus used on the soil is in the form of acid phosphate, there is opportunity for choice among this material, bone meal and basic slag,



Acid phosphate — No fertilizer

FIG. 25.—"As a rule, after the soil has been under cultivation for a period of 25 years or more, the crops grown on it will respond very markedly to applications of phosphatic fertilizers." Ohio Experiment Station Farm at Strongsville.

the three products which carry this element in the most readily available forms. These three materials vary in their effectiveness, depending upon the conditions of the test. Bone meal contains a higher percentage of calcium than does acid phosphate and will be relatively more effective on acid soils. On the other hand, acid phosphate contains soluble phosphates which tend to precipitate aluminium and thereby to overcome the toxicity of this element. Basic slag has considerable capacity to neutralize

acid soils and for that reason is often preferred on pastures or on alfalfa where lime may not have been added. There is also an additional complication in that acid phosphate contains considerable amounts of calcium sulphate. It is necessary in comparative trials to take these facts into consideration.

An interesting comparison of these three carriers of phosphorus is provided by the tests on the Ohio Agricultural Experiment Station farm at Wooster. In these tests, 14 per cent acid phosphate is supplied at the rate of 320 pounds per acre each five-year period and the other materials are used in equivalent amounts. The rotation is corn, oats, wheat, clover and timothy, the phosphate, together with supplemental nitrate of soda and muriate of potash, being applied to the soil for the first three crops in the rotation. The soil, Wooster silt loam, is limed as required.

TABLE LXXIX

COMPARATIVE EFFECTIVENESS OF VARIOUS CARRIERS OF PHOSPHORUS SOIL LIMED AND TREATED WITH NITRATE AND POTASH—1900–1918

Increase from Phosphorus Carriers Calculated on Basis of Acid Phosphate at 100

Carriers of Phosphorus	Corn	Oats	Wheat	Clover	Timothy
Acid phosphate	100	100	100	100	100
Bone meal .	53	54	67	113	115
Basic slag	53	52	78	85	65

In general, the acid phosphate seems to be the most effective and basic slag the least effective in increasing crop yields. Other comparative tests on a potato-wheat-clover rotation at Wooster showed somewhat more favorable ratios for bone meal and basic slag, particularly the latter. Undoubtedly much would depend upon the conditions of the test. All three of them have been found to be good investments.

In the above test these three carriers of phosphorus have been compared on the basis of equivalent amounts of what is considered to be "available" phosphorus. The test of availability as applied to acid phosphate has been given previously. With bone, the total content of phosphorus is determined with no supplemental solubility tests. With basic slag the test is one of solubility in 1 per cent citric acid solution. The comparisons, therefore, have been made somewhat arbitrarily, but are of value in giving a clue to the relative effectiveness of the phosphates under conditions in which the lack of lime has not been a limiting factor.

THE CALCIUM SULPHATE IN ACID PHOSPHATE

In the early analyses of plant ash a considerable part of the sulphur was lost by volatilization in the process of incineration. This fact not being known, the importance of the element sulphur in soil and plant economy was not appreciated. Recently it has been shown that the content of sulphur in plants and soils is quite similar to that of phosphorus and the problem of economy of the two elements may be assumed to be much the same. However, there are several points at which it differs. Sulphates are readily leached from the soil. Sulphur is not required in such large amounts as phosphorus in animal economy. There is a sulphur cycle by way of the atmosphere which renews the supply in the soil, at least in industrial sections, as rapidly as it is depleted by crops.

The beneficial effects of landplaster, particularly on somewhat unproductive soils and on the legume crops, has long been known. Benjamin Franklin is said to have written " This land has been plastered " on a hillside near Philadelphia with landplaster and the words could be read by the passerby because of the remarkable increase in the growth of the grass. At one time landplaster was quite a popular fertilizer, but later its use fell into disrepute when

the good effects of limestone and later of acid phosphate became known. Since the latter material contains landplaster, it is difficult to determine what part of its effectiveness is due to this material and what part to its content of available phosphorus. In the manure test previously cited it was shown that landplaster added to the manure, increased its effectiveness. It is possible that a mixture of phosphate rock and landplaster would have given, under some conditions, results quite as good as acid phosphate.

With the development of the "treble superphosphate" industry there is an additional reason for determining the extent to which the calcium sulphate in the acid phosphate functions in its effectiveness. The concentrated acid phosphates contain very little or no calcium sulphate. Under conditions in which the lack of sulphur is a limiting factor in crop growth, it is probable that it will be desirable to continue to use acid phosphate carrying at least a certain percentage of calcium sulphate. It is possible that as these investigations continue it may be shown that gypsum, of which large quantities are available, may be used in connection with phosphate rock, bone meal and basic slag to advantage.

FINENESS OF GRINDING PHOSPHATE FERTILIZERS

With either phosphate rock, bone meal or basic slag, fineness of grinding is essential to rapid availability. It is for this reason that control bulletins often show the fineness of bone meal. Steamed bone is usually much more finely divided, and therefore more effective, than the raw bone. Phosphate rock is ordinarily pulverized to the point where most of it will pass a sieve with 200 meshes to the inch. Since phosphate rock contains its phosphorus in a form quite similar to that of apatite, which is the mineral containing the phosphorus in the soil, no considerable increase in the amount of available phosphorus can be expected in the soil solution from its use, unless a large amount of fresh sur-

face of the phosphate rock is exposed to the solvent action of the soil water.

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CHAPTER XXIII

POTASSIUM FERTILIZERS

Soils containing fairly high percentages of silt and clay are usually well supplied with potassium, the quantity contained in two million pounds of average surface soil amounting to 35,000 pounds or more. In contrast with nitrogen and phosphorus, the potassium content of subsoils is usually somewhat higher than that of the surface soil. Considered from the point of view of the entire depth of soil through which the roots of crops penetrate, the amount of potassium is such that there is little danger of exhaustion of this element. On the other hand it has been shown that most soils which have been farmed for a quarter of a century or more will produce considerably larger yields of most crops if some soluble potassium salt, such as the chloride or sulphate, is applied to them. It would appear that most of the potassium contained in the soil is present in a form which does not readily dissolve in the soil water.

AVAILABLE POTASSIUM IN SOILS

Most of the potassium in soils occurs in the form of silicates in various stages of hydration and decomposition. An additional amount is probably present in the form of adsorption compounds. Freshly pulverized orthoclase yields an alkaline solution on shaking with carbonated water due to the formation of potassium carbonate. The rate of solution of potassium from soils containing only small amounts of organic matter is relatively slow. Evidently, as the process of hydrolysis continues, secondary mineral

products are formed which either hold their potassium firmly adsorbed or are covered with a protective coating of colloidal material which serves to shield the undecomposed mineral from further action of the soil solution.

The available potassium in soils is probably largely that which is present in combined form in plant remains from which it readily dissolves or is liberated through the action of bacteria. The decay processes undoubtedly also aid in the liberation of additional potassium through the production of strong mineral acids, such as nitric and sulphuric, which may have opportunity to act on the previously undecomposed potassium-bearing minerals in the soil. Under good systems of management in which the soil is kept well supplied with crop residues, such as manure or clover roots and stubble, large crop yields can be produced almost indefinitely without the supplemental use of soluble potassium salts. In the livestock system of farming, in which the loss of potassium from the farm in the form of animals or their products is practically *nil*, it should be possible to keep such potassium, as has once been dissolved, in the form of "circulating capital." The drainage losses of potassium are not as large as the solubility of its compounds would lead one to believe, since, as previously noted, the soil has a high adsorptive capacity for this element.

SOILS NATURALLY DEFICIENT IN POTASSIUM

There are soils, however, in which even with good management the lack of available potassium is likely to be a limiting factor in crop growth unless it is supplied in manure or in commercial form. The most outstanding examples of such soils are found in certain peats and mucks and in sandy soils containing a high percentage of quartz. On such soils the response of crops to the use of soluble salts of potassium is often quite remarkable. Examples of such cases are given by Conner and Abbott in connection with a study of some unproductive black soils of Indiana. The following table

shows the effect of potassium-bearing fertilizers on the yields of onions on some of these soils:

TABLE LXXX

EFFECT OF POTASSIUM SALTS ON ONION YIELDS ON BLACK SOILS, INDIANA

County	Unfertilized Yields, Bushels per Acre	Bushels Increase from Fertilizer *	
		No Potash	10 Per Cent Potash
Benton	606	75	113
Kosciusko	353	41	66
Whitley	307	20	130
Jasper	423	12	202
Noble	391	47	89
Average all tests	404	49	130

* 1000 pounds of fertilizer per acre

A similar test with potatoes on a sandy loam soil in Florida is reported by Floyd and Rupert with the following results:

EFFECT OF POTASSIUM SALTS ON POTATO YIELDS ON SANDY SOILS, FLORIDA
Bushels per Acre with 2000 Pounds Fertilizer

Year	No Potash	5 Per Cent Potash
1918	34	69
1919	76	119
1920	100	146
Average	70	111

SOILS DEPLETED OF AVAILABLE POTASSIUM

Even on soils containing large amounts of total potassium, continued cropping without the return of manure or adequate amounts of crop residues soon leads to a reduction

in yields because of the lack of this element. An interesting example of such a case is found in the data of the Ohio Agricultural Experiment Station in connection with the growing of potatoes, wheat and clover in rotation, on a silt loam soil containing over 30,000 pounds of the element potassium in the plow depth of surface soil. In these tests which have extended over a period of twenty-five years, a comparison has been made between two fertilizers, one of which contained only acid phosphate and nitrate of soda, and the other an additional quantity of muriate of potash. These fertilizer materials were applied at the rate of 320, 240 and 200 pounds per acre, respectively, with the following results:

TABLE LXXXI

EFFECT OF POTASSIUM SALTS ON YIELD OF CROPS ON WOOSTER SILT LOAM SOIL

Three-Year Rotation—Soil Limed and Fertilized—1894 to 1918

Period	Treatment	Increase in Yield per Acre from Fertilizers		
		Potatoes, Bu	Wheat, Bu	Clover, Cwt
1894–1905	No potassium	20.9	7.1	2.8
1894–1905	With potassium	17.0	9.2	2.1
1906–1917	No potassium	12.2	8.5	7.8
1906–1917	With potassium	44.7	10.5	10.0
1894–1905	No fertilizer yield	165.8	25.5	35.5
1906–1917	No fertilizer yield	103.8	26.8	31.9

At the beginning of the test the soil was in a virgin state having been recently cleared from second growth forest. A sufficient amount of potassium was made available, as a result of cultivation and through the processes of decay, to satisfy the requirements of the crops grown, so that the limiting factor was something other than the lack of available potassium. Later a deficiency of this element

became apparent in the yields of potatoes with minor evidence in the wheat and clover. It should be mentioned that the disease factor interfered with the success of the potato crop during the later years of the test when it became

2 tons silage 14.5 tons silage
Corn on muck land at Evansville, Wisconsin

FIG. 26.— "There are soils in which, even with good management, the lack of available potassium is likely to be a limiting factor in crop growth unless it is supplied in manure or in commercial form. The most outstanding examples of such soils are to be found in certain peats and mucks and in sandy soils containing a high percentage of quartz."

necessary to substitute corn for potatoes every second time around the rotation.

THE SOURCE OF POTASSIUM FERTILIZERS

The potassium in fertilizers has its origin largely in natural salt deposits of which those in France and Germany are by far the most extensive known. Previous to the World War most of the potash salts used in America came from the Stassfurt mines in Germany. These deposits are made up largely of chlorides and sulphates of sodium, potassium, magnesium and calcium. Two crude salt mixtures known as kainit and manure salts and containing 12.5 and 25 per cent, respectively, of potassium oxide, ordinarily termed potash, are used in considerable amounts without being refined. Most of the potassium shipped to America, however, is in the form of the sulphate or

the muriate of potash containing 48.6 and 50 per cent of potash, respectively.

The total importations of potash salts had reached large proportions as indicated in the statistics given below for the year 1913, immediately preceding the War:

TABLE LXXXII

IMPORTS OF POTASH SALTS INTO THE UNITED STATES IN 1913

Salts	Per Cent Potash	Tons of Salt	Tons Potash
Kainit	12 4	521,176	64,626
Manure salts	20 0	250,529	50,106
Muriate of potash	50 0	237,630	118,815
Sulphate of potash	48 6	44,319	21,554
All others		38,904	15,619
Grand total, 1913	..	1,092,588	270,720
Grand total, 1918	.	24,419	7,957

The importations of potash salts were very small during the War and as a result a considerable advance was made in the recovery of potash as a by-product in manufacturing processes and from natural brines in the United States. Waggaman gives the data for this as indicated below:

TABLE LXXXIV

QUANTITIES OF POTASH PRODUCED IN AMERICAN INDUSTRIES, 1918

Name of Industry	Material Produced	Tons of Material	Percentage Potash
Potash from brines	Crude potash salts	89,371	28.0
Potash from alunite	Sulphate of potash	6,180	42 0
Iron blast furnaces	Flue dust	1,500	20 0
Cement industry	Flue dust	11,172	12 0
Beet sugar industry	Factory waste	3,650	20 0
Tobacco industry	Tobacco stems	37,200	4–6
Kelp industry	Muriate of potash	14,029	34
Wool industry	Wool washings	931	12–50
Hardwood industry	Potassium carbonate	1,063	61

Until such time as the natural deposits of potash salts of Germany and France are exhausted a large part of the potassium used for fertilizer and other purposes will probably be from that source unless other natural deposits are found. A number of applications for patents have been filed with the United States Patent Office which have for their purpose the protection of processes of extracting potassium from silicate rocks. The extent to which such processes may be developed in the near future is problematical.

AVAILABILITY TESTS FOR POTASSIUM

The availability test for potassium is solubility in water. The only other laboratory determination concerning potas-

FIG. 27.—"The potassium in fertilizers has its origin largely in natural salt deposits of which those in France and Germany are by far the most extensive known." Drilling holes for cartridges at the end of a working gallery. (Courtesy, Société Commerciale Des Potasses D'Alsace.)

sium made by control chemists is one for the purpose of deciding whether it is present in the fertilizer as the sulphate or the chloride. For certain purposes the sulphate is believed to be preferable to the muriate of potash. Since

the latter is somewhat cheaper and the quantity available is greater there is a tendency for the manufacturer to use it in his mixture, providing no objection is raised by the fertilizer user. Manure salts and kainit also contain large amounts of chlorides.

COMPARATIVE VALUES OF VARIOUS CARRIERS OF POTASSIUM

Kainit and manure salts, by reason of their content of sodium and magnesium salts, probably influence the growth of crops in a variety of ways. Ordinarily, the more concentrated salts are used as a means of economizing on freight. Of the comparisons which have been made of the several carriers of potassium an example may be selected from the tests of the Ohio Agricultural Experiment Station, at Germantown, with the tobacco crop. In these tests potassium was used as the muriate, nitrate and sulphate, in equivalent amounts, in connection with acid phosphate and nitrate of soda, on Miami silt loam soil, for the tobacco crop grown in rotation with wheat and clover. Nitrate of potash is a by-product of the tobacco industry. The nitrate of soda, acid phosphate and muriate of potash were applied to the soil, previous to planting the tobacco, at rates of 240, 480 and 180 pounds per acre respectively. The data for the period 1903-1918 follow:

TABLE LXXXV

COMPARATIVE EFFECTIVENESS OF VARIOUS CARRIERS OF POTASSIUM
3-YEAR ROTATION—MIAMI SILT LOAM SOIL—FIFTEEN-YEAR AVERAGES
BASIC TREATMENT OF ACID PHOSPHATE AND NITRATE OF SODA

Increase from Potassium Carriers Calculated on Basis of Muriate of Potash at 100

Carrier of Potassium	Tobacco	Wheat	Clover
Muriate of potash	100	100	100
Nitrate of potash *	73	152	34
Sulphate of potash	71	148	162

* In this case the nitrate of soda was reduced to 80 pounds per acre

The yield of tobacco was greater from the use of the chloride than from either the nitrate or sulphate, but its quality for smoking purposes was somewhat inferior. Similar objections have been raised against the use of muriate of potash in connection with the growing of potatoes, although Wheeler states that tubers of excellent cooking quality have been grown for many years on the Rhode Island Agricultural Experimental Farm with muriate of potash as the sole source of the commercial potassium.

SODIUM AS A SUBSTITUTE FOR POTASSIUM

During the World War, interest was revived in the possibilities of substituting sodium for potassium salts in fertilizers. This subject had long been a matter of investigation and controversy. As early as 1894 a series of plots had been set aside for the study of this problem at the Rhode Island Agricultural Experiment Station. The last

TABLE LXXXVI

The Substitution of Sodium for Potassium in Fertilizers

Ratios of Oxides		Relative Yield of Crops	
Soda	Potash	Radishes *	Potatoes †
1	0	40	17
¼	¼	70	61
1	¼	80	61
½	½	93	80
1	½	95	81
¾	¾	101	97
1	¾	104	81
0	1	100	100
¼	1	102	101
½	1	104	105
¾	1	106	93
1	1	102	95

* 1-year average. † 5-year average.

report on these investigations, covering the period from 1905 to 1918, is given by Hartwell and Damon. In these tests the sodium and potassium were supplied both as carbonates and as chlorides and in connection with two different amounts of lime. Phosphorus and nitrogen were supplied in such amounts as were assumed to make the lack of potassium the limiting factor. In Table LXXXVI are given the relative yields of radishes and of potatoes as determined by the extent to which sodium salts replaced the potassium salts in the fertilizer mixture.

The authors conclude that sodium can be substituted in part for potassium in the plant. A further indirect benefit is secured probably due to the replacement by the former of the potassium in the soil compounds and also, perhaps, as a result of the similarity of the salts of these two elements as related to their effect on the soil solution.

MAKING SOIL POTASSIUM AVAILABLE

Because of the large amount of potassium in the average soil and subsoil, considerable attention has been given to the means by which this can be made available. In addition to sodium, such elements as magnesium and calcium may be assumed to have the capacity to replace potassium in the adsorption or mineral compounds in which it exists in the soil. The use of lime, particularly in the oxide and hydrate forms, has been suggested for this purpose, but the data on the subject are conflicting. A résumé of the results of such investigations is given by Briggs and Breazeale. Hopkins and Aumer found that even after all of the potassium, which was soluble in strong hydrochloric acid, had been extracted from a soil, additional amounts gradually became available, by growing crops of clover and turning them under. Green manuring crops and weeds, particularly those having large fibrous root systems, may function in part as agents for extracting potassium from the soil for the use of subsequent crops. In connection with

his investigation of the feeding power of plants for phosphate rock, Bauer also studied their capacity to utilize the potassium of feldspar. He found that as compared with the normal at 100 when supplied with soluble potassium salts, buckwheat, corn, sweet clover and oats produced a percentage growth of 23, 45, 106 and 107, respectively, when the source of potassium was feldspar.

On livestock farms most of the potassium removed in crops can be returned to the soil in the manure and in a form which is soluble in water. If such a crop as sweet clover is grown in the rotation, it is possible that a considerable supply of potassium may be made available for the use of other crops. All of these methods of making soil potassium available must be weighed as to cost against the more simple process of applying soluble potassium salts in forms and amounts to suit the needs of the crops to be grown. In intensive systems of farming and with crops having a high potassium requirement and a high acre value, there is little question but that the latter method is essential and profitable as a supplement to any other means which may be employed for extracting this element in larger amounts from the soil.

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CHAPTER XXIV

MIXED FERTILIZERS

THE carriers of nitrogen, phosphorus and potassium can be purchased and applied separately or they can be secured in the form of mixed fertilizers and the entire application made at one time. In general, the American farmer prefers to apply his fertilizers all in one operation. Even if he buys the ingredients separately they are usually mixed before being applied to the soil. While a certain amount of home-mixing is done, the major portion of this work has been taken over by the fertilizer manufacturers, who should be able to do it more economically and in many ways better than the farmer. The disadvantage in using mixed fertilizers, other than the fact that their cost is higher, due to the inclusion of a mixing charge, lies in the opportunity afforded the manufacturer to put into the mixture some of the less desirable carriers of the nutrient elements.

THE FUNCTION OF THE CONTROL CHEMIST

Practically all of the states have laws regulating the sale of fertilizers which make it compulsory for the manufacturer to state on the bag, or on a tag attached thereto, the sources of the fertilizer elements and the percentages and solubilities of these elements. Each of these states has in its employ a control chemist whose function it is to see that the guarantees of the several companies are met in the mixtures which they sell, both as to percentage and availability of the essential elements contained in them. Previous discussion has shown that the solubility tests for

phosphorus and potassium seem to indicate availability fairly satisfactorily. There is somewhat more uncertainty as to the solubility tests for nitrogen. As a rule, however, the intelligent buyer is protected by the inspection service, the report of which shows the claims of the fertilizer manufacturer and the findings of the control chemist The opportunity for the use of materials of low availability is less in high analysis fertilizers since these usually contain the fertilizer elements in such small percentages that high analysis mixtures cannot be made from them.

"WET MIXED" FERTILIZERS

One of the arguments of the fertilizer manufacturers in favor of factory mixing of fertilizers is that by this means an outlet is provided for all kinds of waste products of plant and animal origin which have little or no value for any

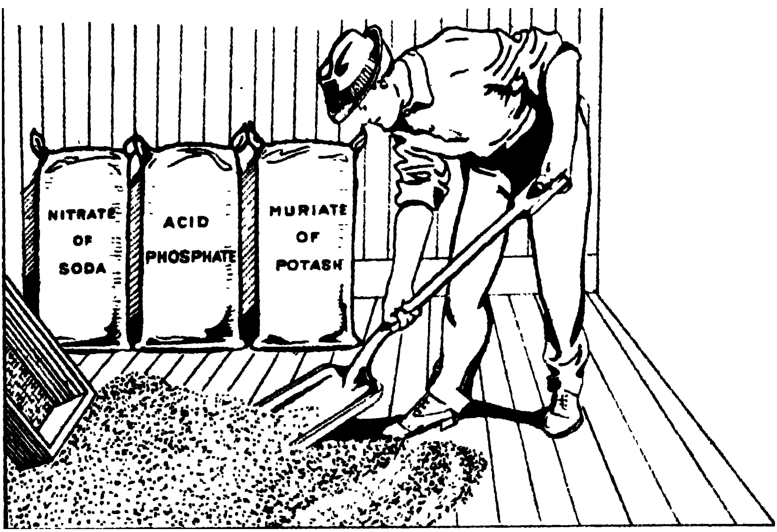


FIG. 28.—"While a certain amount of home-mixing is done, the major portion of this work has been taken over by the fertilizer manufacturers, who should be able to do it more economically and in many ways better than the farmer."

other purpose. In the " wet mixing " process these organic by-product materials are mixed with the phosphate rock and the mixture is treated with sulphuric acid. After being processed in a " silo," allowed to cure, taken out and pulverized, the resulting material contains its nitrogen as well as phosphorus in more available form. The work of Hartwell and Pember, previously referred to, shows the effectiveness of this process. Many of the factories are simply dry-mixing plants and the organic materials are therefore not processed. This will be shown by the solubility tests of the control chemist in states in which such tests for quality of nitrogen are made. However, the fertilizer industry is becoming each year more of a chemical and less of a scavenger industry, and an ever-enlarging percentage of the ingredients are inorganic compounds carrying the fertilizer elements in highly available forms.

An excellent discussion of the problems involved in the fertilizer business is given by Hills in which it is shown that, on the whole, the manufacturers are rendering a valuable service to the farmer in taking over the entire problem of assembling and compounding the several fertilizer ingredients into mixtures of good mechanical condition and meeting the requirements of the crops to be grown.

HOME-MIXING FERTILIZERS

In the event that the mixing charge is too high the farmer has the alternative of mixing his own fertilizers. These can be put together in ratios to suit the requirements of each crop. As a result of the activities of the fertilizer industry it has become customary to speak of fertilizer analyses in terms of their content of ammonia, phosphoric acid and potash. Thus a 3-12-4 fertilizer is one which contains 3 per cent of total nitrogen calculated as NH_3, 12 per cent of "available" phosphorus calculated as P_2O_5, and 4 per cent of water-soluble potassium calculated as K_2O. Assuming that such a fertilizer was to be mixed by the

farmer, he would ordinarily purchase nitrate of soda, acid phosphate and muriate of potash as his sources of these compounds and mix them in the following proportions:

TABLE LXXXVII

INGREDIENTS FOR ONE TON OF 3-12-4 FERTILIZER

Carrier	Compound	Per Cent	Pounds Required
Nitrate of soda	NH_3	19	316
Acid phosphate	P_2O_5	16	1500
Muriate of potash	K_2O	50	160
Filler	...		24*
Total			2000

* The filler may be omitted and the fertilizer application reduced accordingly

The fertilizer manufacturer could, if he desired, so select his materials as to secure the correct percentages without the use of any filler. Usually he finds it desirable either to use an organic carrier for part of the nitrogen or to add a small amount of some inert material, such as sand or muck, in order to insure that the mixture will not become hard on standing. Lime and limestone have often been employed for this purpose and are very effective, although if used in any considerable amounts they tend to reduce the availability of the phosphoric acid and to cause the volatilization of ammoniacal nitrogen.

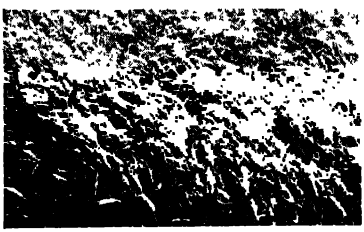
THE USE OF SINGLE FERTILIZER SALTS

It is probable that, with the development of the more intensive and specialized systems of farming, it may be found desirable to utilize the several fertilizer materials at different periods in the growth of the crop. Thus in orchards and vineyards it is customary to apply nitrate of soda or some other readily soluble carrier of nitrogen early in the spring

No fertilizer, 12 bushels *

Acid phosphate, 20 bushels.*

Acid phosphate and nitrate of soda, 25 bushels *



Acid phosphate, nitrate of soda and muriate of potash, 28 bushels *

FIG. 29.—"Each of the materials added to the productive capacity of the soil and the net result of their combined use was the production of large average yields." *

* Twenty-five year average acre yields, Ohio Agricultural Experiment Station

season, while phosphate and potash fertilizers are applied at some other convenient time for the benefit of the mulch- or cover-crop. Similarly, soluble nitrogen carriers are sometimes applied to wheat in the spring, while the other fertilizers are applied at the time of seeding in the fall. By this means it is possible to more nearly fit the application to the needs of the crop as determined by the seasonal factors and the condition of growth of the crop. Such practices are common in Europe and are likely to become much more so in America.

By far the most common practice in general farming systems in America is that of confining the fertilizer to some carrier of phosphorus and depending upon the air for nitrogen and the soil for potassium. Undoubtedly similar practices account for the waves of unpopularity experienced by lime and landplaster. The continued use of any single fertilizer or liming material tends toward a relative accumulation of the elements contained in that material with the result that, unless care is taken to insure the presence of adequate amounts of the other elements required by crops, the single material applied will eventually become ineffective. Fortunately acid phosphate contains not only phosphorus but also calcium and sulphur. Further, it happens to be useful on acid soils and tends to stimulate nitrogen fixation by legumes and the non-symbiotic organisms. Undoubtedly the experiences of farmers with lime and landplaster will not be duplicated so extensively with acid phosphate, although it is probable that many farmers would find that carriers of nitrogen and potash could be used to advantage to supplement the phosphates on much of the soil which has been farmed for fifty years or more, unless a well-managed livestock or a leguminous-green manuring system is practiced.

THE ADDITIVE EFFECT OF FERTILIZER SALTS

It is interesting to note the more or less additive effects of lime and the several fertilizer salts. This is well shown on the silt loam soil of the Ohio Agricultural Experiment Station at Wooster. The soil of this farm had been depleted of its virgin productivity before the fertilizer tests were begun. After some years of experimenting it was discovered that the soil also required lime. From this date forward lime or limestone was applied regularly as required. The following table shows the data of average yields produced for the period 1900–1918, on various plots receiving lime and the several fertilizer salts:

TABLE LXXXVIII

ADDITIVE EFFECT OF VARIOUS FERTILIZER SALTS

Average Acre-Yields, Wooster Silt Loam Soil, 1900–1918

Additional Treatment	Pounds†	Corn, Bu.	Oats, Bu.	Wheat, Bu.	Clover, Cwt.	Timothy, Cwt
None	.	25 6	30 0	12 2	11 6	22 0
Limestone	4000	31 3	35 2	15 7	17 8	30.5
Acid phosphate *	320	39 3	46.3	24 9	25 5	37 9
Nitrate of soda *	480	45 9	50 5	30 5	31 5	40 2
Muriate of potash *	260	54 4	53 2	32 2	33 2	40 9

* Applied in addition to all those mentioned above it.
† Pounds per acre each five-year period.

It is not the purpose, at this time, to consider the ratios of the several fertilizer materials best suited to the needs of the crops grown or which would yield the largest acre return on the investment. The data show that each of the materials added to the productive capacity of the soil and that the net result of their combined use was the production of large average yields of the crops grown in the rotation. Undoubtedly the use of more suitable ratios and of greater total quantities would have resulted in larger

and more economic yields. It must also be kept in mind that no manure was applied to the soil and that the rotation followed does not meet the requirements of good soil practice.

THE GROWTH OF THE FERTILIZER INDUSTRY

Similar data could be found on almost every experimental farm in America the soil of which had been under cultivation for twenty-five years or more before the test was begun. As a result there has been a very rapid increase in the use of fertilizers, a large portion of which have been of the mixed variety. The following table gives the estimated tonnage of fertilizers, including both unmixed and mixed, which was consumed in the United States and in a few representative individual states as given in the American Fertilizer Handbook for 1920:

TABLE LXXXIX

FERTILIZER CONSUMPTION IN TONS IN THE UNITED STATES, 1912-1919

Year	United States	Georgia	Massachusetts *	Ohio *	Kansas
1912	5,981,000	1,103,000	48,000	151,000	5,000
1913	6,560,000	1,120,000	51,000	183,000	7,300
1914	7,367,000	1,282,000	51,000	203,000	9,400
1915	5,586,000	872,000	56,000	225,000	10,000
1916	5,407,000	711,000	53,000	187,000	7,900
1917	6,221,000	895,000	61,000	165,000	7,600
1918	6,778,000	923,000	68,000	219,000	8,000
1919	6,927,000	990,000	61,000	305,000	16,900
Square miles of land	2,973,774	59,265	8,266	11,040	82,158

* Estimates from information by state officials and fertilizer companies

The rapid growth of the fertilizer industry is assured. Many of the problems which are of most concern in their economical use remain to be solved. Some of these have been suggested in previous chapters and others will be dis-

cussed later. It is apparent that farmers are convinced that the various materials which enter into the composition of fertilizers perform a useful function, or functions, in the soil and crop.

FERTILIZER PRACTICE IN OTHER COUNTRIES

European countries also use fertilizers in large amounts. In fact the practice was begun as a result of the investigations and teachings of Liebig in Germany, of Lawes and Gilbert in England and of Ville and Boussingault in France. As previously mentioned, fertilizers are not mixed in factories in Europe as they are in America, but they are usually applied separately or, if mixed, the mixing is largely done on the farm.

The only countries in which agriculture has been carried on successfully over a long period of years without the use of fertilizers are China and Japan. A most interesting discussion of the methods of soil management employed in these Oriental countries is given by King in his book entitled "Farmers of Forty Centuries," from which it is evident that the plan employed by the farmers of these countries does not differ in principle from that of America. The difference is one of method since in China and Japan every bit of human excrement is carefully saved and returned to the field in the place of the mineral fertilizers used in Europe and America.

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CHAPTER XXV

THE SELECTION OF FERTILIZERS

As previously indicated, practically all soils which have been under cultivation for twenty-five years or more have their productive capacity improved by the use of well-chosen fertilizers. Usually, the carriers of nitrogen, phosphorus, potassium and the alkaline calcium compounds are somewhat additive in their effects so that by their combined use the yields of crops can be raised to a very high level. The problem before the farmer is that of deciding on the ratios of these elements best suited to the needs of his crops and as to the quantities to apply. It is evident that the soil, the climate and the crop must receive consideration in reaching a decision. There is a further economic problem involved which may make it necessary to sacrifice yields for profit. This factor may affect both the ratios and the amounts of the several elements which are applied.

THE SOIL FACTOR

Certain general principles may be stated which govern the choice of fertilizers in so far as this is related to the character of the soil. Chemical analyses checked by many tests of fertilizers have shown that most of the soils of the United States are relatively deficient in phosphorus. It is for this reason that phosphates have become so popular, particularly in the general farming areas in the Central West. It has also been definitely established that sandy soils are usually low in their content of available mineral elements and nitrogen. This is particularly true of cer-

tain beach sands which are often made up of almost pure quartz particles. Muck and peat soils are high in their content of nitrogen, but quite often contain only relatively small amounts of potassium. Acid peats are also especially deficient in their content of phosphorus. Soils of sandstone and shale origin usually contain very little carbonate of lime, and associated with this condition is a reduced availability of the nitrogen and mineral nutrients. All soils in the humid regions tend to become acid when put under cultivation.

THE SYSTEM OF SOIL MANAGEMENT

The management of the soil, as related to the system of cropping and the method of disposal of these crops, is of primary importance in determining the extent to which the soil can be made to yield up the required elements to plants. The well-known beneficial effect of legumes in aiding in the conservation and increase of nitrogen in the soil makes it essential to take into consideration the frequency with which such crops appear in the rotation. If the crops grown are fed on the farm and the manure is carefully conserved and returned, the loss of mineral elements and of nitrogen may be reduced to the minimum and the requirements of large crop yields can be met for many years without the use of any commercial fertilizers except phosphates. If, in addition, supplemental feeds are purchased, the productivity of the soil may be still further increased and the expenditure for fertilizers may be confined to that necessary to maintain a proper ratio of the nutrient elements. In grain farming, it is possible to have a system of soil management which corresponds in its effectiveness to that of livestock farming, by growing a legume crop to plow under and returning the straw and stover of the grain crops to the soil.

DEFICIENCIES IN PHOSPHATE AND CARBONATE OF LIME

As previously indicated, no matter whether a livestock or a well-managed grain system of farming is practiced, it becomes necessary in time to supply phosphates to most of the soils of the United States as a means of returning the phosphorus removed in the grain, or in the bones and milk of the animals sold from the farm. It is also essential, as a rule, that limestone be regularly applied in amounts sufficient to compensate for the loss of carbonates in the drainage and crops and to maintain the soil reaction at a point which will meet the requirements of the crops grown. The nitrogen and potassium economy under either of these systems of soil management can be satisfactorily provided for, since conditions are favorable for both the symbiotic and non-symbiotic nitrogen-fixing organisms, and the available potassium may be largely returned in the crop residues and manure.

THE CLIMATIC FACTOR

The various factors influencing the rate of growth of plants are definitely interrelated. Of these factors the climatic group, previously mentioned, are highly important and have a controlling influence in the distribution of crops. Temperature and rainfall, particularly the rainfall-evaporation ratio, operate as limiting factors in crop growth in either extreme. If all other factors are at the optimum, higher temperatures, within certain limits, increase the rate of biological activities, both in the soil and in the plant. Chemical reactions ordinarily double for every increase in temperature of 10° C., although no such increase is noted in the rate of growth of plants with rising temperatures. However, most of the biological processes in the soil are much more rapid in warm climates providing they are not held in check by the lack of water or some other limiting factor.

Bear concludes that nitrogen fertilizers are likely to be more effective, under average conditions, in the latitude of Wisconsin and Georgia than in that of Ohio. In the northern states the soil does not warm up so early in the spring and the seasons are short. Nitrification is therefore delayed and is not likely to be excessive. Quite the opposite is true in the Southern States. This greater nitrogen loss

FIG. 30.– "It is evident that the soil, the climate and the crop must receive consideration in reaching a decision as to the fertilizer analysis to use. There is a further economic problem involved which may make it necessary to sacrifice yields for profit." (Courtesy, Pennsylvania Agricultural Experiment Station.)

could undoubtedly be compensated for by an increased rate of nitrogen fixation, under conditions in which advantage was taken of the more rapid growth of leguminous crops. Truog states that more limestone is required in cool climates by reason of its relation to crop maturity. He also states that weathering processes are more active in the South and more lime is made available from the soil.

Hall calls attention to the value of phosphatic fertilizers

in wet seasons, as a means of hastening the maturity of the crop. This effect has been rather generally noted, particularly in connection with the use of acid phosphate. Hall further states that in dry seasons potash salts, by inducing a longer period of growth, tend to be more effective in increasing the crop yield. In regions of sparse rainfall and in dry seasons, even in humid climates, large applications of soluble fertilizer salts may increase the rate of growth and transpiration of crops to such an extent as to make the lack of water a seriously limiting factor. It is thus apparent that both the composition of the fertilizer and the rate of application will be influenced by the climatic factors. This is one reason why the fertilizer recommendations, even for the same crops and for soils of similar characteristics, differ in the various states.

VARIATIONS IN CROP REQUIREMENTS

It is well known that crops vary in their mineral requirements. This is indicated by the fact that they are found to contain very different amounts of the several soil elements per unit of dry weight or per acre of crop. There is also the additional complication in that they differ considerably in the spread and character of their root systems and consequently in their capacity to secure materials from the soil. These differences were noted in connection with the discussion of the use of phosphate rock and feldspar as fertilizers. It is also a well-known fact that some crops respond much more vigorously to the use of fertilizers, or to one or the other of the several salts of which fertilizers are made, than do others.

Hartwell has presented a preliminary classification of crops, on the basis of their experimental response to the three fertilizer elements ordinarily considered, as indicated in Table XC.

TABLE XC

RESPONSE OF CROPS TO FERTILIZER ELEMENTS (HARTWELL)

Grouped According to Order of Response *

Group	Nitrogen	Phosphorus	Potassium
I	Rye Bean Corn Cucumber Cabbage Pea Potato	Carrot Buckwheat Millet Oat Pea Bean Tomato	Corn Rye Cabbage Turnip Bean Oat Pea
II	Wheat Sunflower Turnip Tomato Beet Carrot Oat	Corn Potato Rye Wheat Sunflower Barley Lettuce	Millet Wheat Buckwheat Carrot Potato Tomato Barley
III	Millet Parsnip Buckwheat Lettuce Barley Squash Onion	Cabbage Beet Cucumber Onion Parsnip Squash Turnip	Squash Sunflower Beet Onion Parsnip Lettuce Cucumber

* In the above table those crops in Group I show the greatest response to the elements indicated.

THE ECONOMIC PHASE OF THE PROBLEM

In deciding as to the fertilizer analysis, Hartwell, of necessity, takes into consideration the matter of economy. He suggests a standard ratio of 2-3-2 for the ammonia, phosphoric acid and potash, respectively, and multiplies this by the number of the group in which each crop is found for each of these compounds in order to arrive at a conclusion as to the most suitable fertilizer analysis. On this basis onions and parsnips would be given a 6-9-6, pota-

toes a 3–9–6, corn a 3–9–3 and cabbage a 2–9–2 analysis, etc.

In the growing of the more specialized crops little attention is paid to the " bank account " method of calculating the necessary return of mineral elements and nitrogen, but large amounts of complete fertilizers are supplied, since there is opportunity for additional profit either by reason of a greater yield, a better quality, or the possibility of getting the product on the market earlier than most competitors. The relationship between the acre value of crops and the possibilities from the use of fertilizers are indicated in the following table. In this table the assumption is made that a 10 per cent increase in crop yield will result from the use of a fertilizer. The last column shows the number of pounds of fertilizer costing $40 per ton which could be purchased from the proceeds of sales of the 10 per cent increase of each crop.

TABLE XCI

ACRE VALUE OF CROPS AS RELATED TO EXPENDITURES FOR FERTILIZERS

Calculated from 1920 Average Yields and Prices in United States

Crop	Yield per Acre, Bushels	Dec 1 Price	Acre Value	10 Per Cent Increase	Fertiliz Pound
Corn	30 9	$0 677	$20 92	$2 09	105
Wheat	13 8	1 443	19 91	1 99	100
Oats	35 2	0 472	16 61	1 66	83
Potatoes	109 6	1 161	127 57	12 76	638
Tobacco	796 1	0 211	168 07	16 81	841
Cotton	170 8	0 140	23 91	2 39	120

* Assuming a 10 per cent increase in crop from the use of fertilizers the value of the increase would be equivalent to the cost of the number of pounds of fertilizer indicated when calculated at $40 per ton

The above figures indicate that the farmer could afford to invest in 841 pounds of fertilizer costing forty dollars per ton to secure a 10 per cent increase in the yield of tobacco,

FIG. 31.—No fertilizer.

FIG. 32.—Complete fertilizer.

"In the growing of the more specialized crops little attention is paid to the bank-account method of calculating the necessary return of mineral elements and nitrogen but large amounts of complete fertilizer are supplied since there is opportunity for additional profit either by reason of a greater yield, a better quality, or the possibility of getting the product on the market earlier than most competitors." Cucumbers on Ohio Experiment Station Farm at Marietta.

at the average price indicated, as compared to 83 pounds in the case of oats.

The quantity of fertilizer which can be applied to advantage to any given crop is governed by the relative cost of the fertilizer and the selling price of the crop. This is very well shown in the following table taken from the work of Jordan at the New York State Experiment Station at Geneva. At the time during which the tests were under way fertilizers were relatively cheap, a ton of a 4–8–10 mixture costing, in the unmixed materials, $25. During the period from 1900 to 1920 the December 1st farm selling-price for potatoes in the United States has varied from $0.43 to $1.60 per bushel. Assuming $0.50 and $1.50 as representing low and high prices it will be seen that the value of the increase above the cost of the fertilizers is greatest for a 1000-pound application at the former selling price, but for the 2000-pound application at the latter.

TABLE XCII

SELLING PRICE OF CROP AS RELATED TO QUANTITY OF FERTILIZER

From Data on Increase in Yield of Potatoes with 4-8-10 Analysis

Pounds per Acre	Cost per Acre	Increase, Bushels, per Acre	Value of Increase above Fertilizer Cost	
			At $0.50	At $1.50
500	$6.25	23.3	$5.40	$28.70
1000	12.50	44.2	9.60	53.80
1500	18.75	55.1	8.95	64.35
2000	25.00	61.1	5.70	67.10

STANDARDIZING FERTILIZER ANALYSES

The fertilizer analysis to use depends upon so many variables that it is difficult to make specific suggestions with reference to its selection. The soil, the climate, the crop, the economic factors, including the relative cost of the several ingredients in the fertilizer and the total cost per

ton, and the selling price of the crop are all involved. A study of the investigational work on fertilizers indicates, however, that there is little justification for any very large number of analyses. A committee of agronomists representing Indiana, Missouri, Michigan, Ohio and Wisconsin, in conference, agreed upon 14 analyses which were said by manufacturers to be feasible from the factory point of view and which were believed to meet the needs of the Middle West. Similarly the agronomists of the Middle Atlantic States agreed upon 19 analyses for the conditions which obtain in that region. Later the New England agronomists eliminated all but 9 analyses which were believed to meet the requirements of that region. These lists as adopted follow:

TABLE XCIII

FERTILIZER ANALYSES SUGGESTED BY AGRONOMISTS

To Fit the Needs of the Various Regions

Inorganic Soils

Middle West	New England	Middle Atlantic	
0-12-6	0-12-6	0-12-6	
0-11-4	2-12-4	2-12-2	
2-12-2	4-8-6	2-12-4	
2-12-4	3-10-4	1-8-6	
2-12-6	3-10-6	1-12-0	
2-14-2	1-8-4	3-16-6	
2-16-2	5-1-5	4-8-4	
3-12-4	5-8-7		
3-8-6	8-6-6		
4-8-6			
4-12-0			
Organic Soils			
0-8-24		0-10-10	5-10-5
0-10-10		2-10-6	6-8-4
2-8-16		3-8-3	7-6-5
		3-8-8	0-10-4
		4-12-4	4-8-10
		5-8-5	10-5-0

TABLE XCIV

Suggested Use of Fertilizer Analyses [1]

By Ohio Agricultural College and Experiment Station

Other Treatment	Light-colored Soils [2]			Dark-colored Soils [3]		
	None	Clover [4]	Manure [5]	None	Clover [4]	Manure
Corn, rye	2-12-6	0-14-4	0-16-0[6]	0-14-4	0-16-0	0-16-0
Wheat, oats	3-12-4	2-14-2[7]	0-16-0	2-14-2	0-14-4	0-16-0
Alfalfa, clovers	2-12-6	0-14-4	0-16-0	0-14-4	0-14-4	0-16-0
Soybeans, beans	0-14-4	0-14-4	0-16-0	0-16-0	0-16-0	0-16-0
Potatoes, tobacco	3-8-6	2-12-6	2-14-2	2-14-2	0-14-4	0-16-0
Onions, celery ..	3-8-6	3-12-4	2-14-2	3-12-4	0-14-4	0-16-0
Tomatoes, cabbage	3-12-4	2-12-6	0-16-0	2-14-2	0-14-4	0-16-0
Sugar beets, turnips . .	2-12-6	0-14-4	0-16-0	0-14-4	0-16-0	0-16-0
Timothy, Meadows	3-12-4	2-14-2	0-16-0	4-12-0	0-16-0	0-16-0
Permanent Pastures. . .	0-16-0	0-16-0	0-16-0	0-16-0	0-16-0	0-16-0
Strawberry, raspberry	3-12-4	2-14-2	0-16-0	2-14-2	0-16-0	0-16-0
Grapes, peaches [8]	0-14-4	0-14-4	0-16-0	0-16-0	0-16-0	0-16-0
Apples, pears [8]	0-14-4	0-14-4	0-16-0	0-16-0	0-16-0	0-16-0

[1] The rate of application will vary from 200 to 2000 pounds per acre, depending largely upon the acre value of the crop The fertilizer treatment for crops not mentioned should be that of the most closely related member of the list

[2] For light-colored sands use same analyses but increase the amounts per acre

[3] For black sands and mucks substitute 0-10-10 for 0-14-4, the 0-14-4 for 0-16-0, and the 2-12-6 for the 2-14-2 or 3-12-4, and increase the amounts per acre.

[4] Assuming a ton and a half yield of clover or some other legume preceding the crop to be fertilized If the soil is acid, limestone is essential

[5] On the assumption that the land receives the equivalent of 8 tons of well-preserved manure per acre every 3 years

[6] Acid phosphates 0-18-0, 0-20-0, and higher, where available, may be substituted for the 0-16-0

[7] The 2-12-2 or 2-16-2 may be substituted for the 2-14-2, wherever found in the list

[8] Recommended as basic treatments to insure proper growth of mulch or cover crops Additional spring dressings of nitrate of soda (or its equivalent in sulphate of ammonia) at the rate of ¼ pound for each bearing grape vine or ¼ pound per year of age for each fruit tree are suggested

Undoubtedly these lists of analyses might still be simplified to advantage. It is probable that the relative cost of fertilizer nitrogen and phosphorus will gradually change as the processes of nitrogen fixation are improved and the demand for phosphates increases in the grain-growing lands of the West. It will also be noted that the analyses suggested by the New England Agronomists contain relatively high percentages of both ammonia and potash. While the soil, climatic and economic factors vary in the several regions, it is probable that this does not entirely explain the differences in the suggested lists of analyses. Hartwell states that it is "probable that the current practice of applying phosphorus far in excess of what the crop removes will eventually modify the soil so that the deficiency of phosphorus will not exceed that of the other elements."

Agronomists of several states have made specific suggestions as to the analyses best suited to given crops and soils under the climatic and economic conditions which prevail in their respective states. Of these the suggestions in Table XCIV, distributed by the Agricultural College and Experiment Station of Ohio to the farmers of the state, are selected as being somewhat typical.

THE LAW OF THE MINIMUM

The research method which offers most promise in answering the question as to what analysis to use under any given set of conditions is one which attempts to determine the return for each additional increment of the limiting element, all the others being supplied at an assumed optimum. The problems involved in such a method of study are many, but not necessarily impossible of solution. It is becoming more and more apparent that questions of economy should not enter into consideration in such studies. It is desirable to know at what point, either when supplied in excess or in deficiency, each fertilizer salt becomes a lim-

iting factor. Under any given set of economic conditions it would then be possible to approach a solution as to the most profitable mixture to apply. The following example of such a method of study on corn grown on Miami clay loam soil and under the climatic conditions which prevail at Columbus, Ohio, is given as being suggestive. In this test acid phosphate, muriate of potash and limestone were applied to the soil at what was estimated to be the optimum, the element under investigation being nitrogen. This was applied in the form of sulphate of ammonia. The data follow:

TABLE XCV

EFFECT OF ADDITIONAL INCREMENTS OF A LIMITING FACTOR ON CORN YIELDS

Variable, Sulphate of Ammonia—Other Elements at a Theoretical Optimum

Sulphate of Ammonia, Pounds per Acre	Increase in Acre Yield	
	Grain, Bu	Stover, Cwt
50	-3.7	3.1
100	1.9	2.7
150	9.3	2.6
200	15.6	8.8
400	9.8	10.5
800	8.8	9.5

The curve of increase indicates that the optimum yield would have been produced with an application of something more than 200 pounds of sulphate of ammonia per acre. The most profitable rate of application at the prices which prevailed in 1920, the year of the test, was one which was somewhat less than this amount. With a change in the selling price of the corn or in the cost of sulphate of ammonia, some other rate of application would probably be more profitable.

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CHAPTER XXVI

THE APPLICATION OF FERTILIZERS

THE time and method of application of fertilizers varies with the nature of the fertilizer, the effect which it is desired to have produced, the soil, the crop and the climatic conditions. In the absence of any evidence to the contrary, the farmer applies these materials at the most convenient time. Since distribution of labor is one of the important factors in determining the economy of production of crops, there should be ample evidence in support of any inconvenient time or method of application before it is adopted. This is especially true in general farming where the cost of the fertilizer materials and of their application may be a considerable part of the total cost of producing the crop.

TIME OF APPLICATION OF NITROGEN FERTILIZERS

It will be recalled that availability tests indicate that nitrate of soda is a more efficient carrier of nitrogen than any of the others used in the experimental tests. In the small amounts in which it is ordinarily applied the losses by leaching, if any, are more than compensated for by the greater availability of the nitrate nitrogen.

Keitt believes, from experimental work in South Carolina on the Portsmouth series of soils and under conditions of abundant rainfall, that soluble nitrogen salts, if used, should be applied during the growing period of the crop rather than previous to planting. He suggests the use of small amounts of soluble nitrogen, in addition to the

other fertilizer salts, on oats and cotton at the time of planting as a means of giving the crops a vigorous start, but recommends that most of the nitrogen be applied after the crop is well advanced. The suggestion for the corn crop was that the nitrate of soda be applied when the corn was knee high; for oats during the latter part of February or early March and for cotton during its early fruiting stage.

Nitrogen presents a special problem by reason of the solubility of the nitrates and the fact that the soil has little fixing power for them. The problem is somewhat more serious in sandy soils and in regions receiving abundant rainfall. This is one reason for the suggestion of fertilizer manufacturers, previously discussed, that the nitrogen of mixed fertilizers should be supplied by several different materials differing in the solubility and availability of their nitrogen. Probably Keitt's suggestion of delaying the application of part of the nitrogen until the time when it is most needed and then using the more available carriers is to be preferred, except for the fact that it is not desirable from the point of view of national economy to confine the use of nitrogen to nitrate of soda and to the exclusion of all other carriers.

USE OF NITROGEN FERTILIZERS IN ORCHARDS

It seems rather generally agreed that phosphorus and potassium fertilizers have little direct effect either on the quality or yield of apples or other tree fruits, or on the vine and bush fruits. They do affect the growth of cover crops, particularly the legumes, and will in time, undoubtedly thus indirectly affect the yield and quality of the fruit. It is possible that a much more liberal use of such fertilizers in connection with soluble nitrogen may show direct effects, especially on soils in which the amounts of these elements in available forms are relatively small.

There is still considerable doubt as to what are the causes of fruit bud formation, or as to just what condi-

tions are associated with fruitfulness. The various factors believed to be involved are well reviewed by Gardner and his associates. It seems evident that there must be a rather definite nitrogen-carbohydrate ratio and that when one or the other of these materials is much in excess of the requirements of this ratio, fruit is not produced. Probably other factors are involved, but experiments indicate that usually the limiting controllable factor is the content of available nitrogen in the soil, particularly at certain seasons of the year. Data as to the time of application of nitrogenous fertilizers to fruit trees are somewhat meager, but the general practice is to apply them around the trees just before they start their growth in the spring.

USE OF NITROGEN FERTILIZERS ON WHEAT

Ordinarily, nitrogen fertilizers are applied to wheat at the time of seeding, although some attention has been given to the use of spring applications of nitrate of soda or sulphate of ammonia. More recently considerable interest has been aroused in the discovery that soft wheats can be changed in their characteristics to correspond to the hard wheats by regulating the time of application of nitrate of soda. The following data selected from the work of Gericke are of interest in this connection:

TABLE XCVI

EFFECT OF TIME OF APPLICATION ON PROTEIN CONTENT OF WHEAT

Date of Application, Days after Planting	Protein Content in Per Cent	
	White Australian	Turkey Red
0	8 9	14 6
17– 21	9.2	13 8
33– 36	10 6	14 7
48– 60	11 4	13 4
72– 81	13 0	14 3
109–110	15 2	17 9

The soft spring, Australian wheat grain was quite similar in its characteristics to the hard winter, Turkey red wheat when the nitrate of soda was applied from 72 to 110 days, after planting, and from 121 to 152 days before harvesting. The nitrate of soda was applied at the rate of 100 pounds per acre.

TIME OF APPLICATION OF PHOSPHATES

Both phosphorus and potassium are fixed by the soil and, therefore, are not lost in such large amounts by leaching. This is particularly true of phosphorus since very little of this element is ever found in drainage waters. Notwithstanding the capacity of the soil to absorb these elements from solution, they seem to be readily yielded up to the growing crop as required. This makes it appear logical to apply the salts of these elements in larger amounts and less frequently as a matter of economy of labor. Ordinarily the phosphatic and potash fertilizers are applied at the time of seeding of each crop. Where a crop yielding a high acre return is grown in the rotation on the general farm, it is sometimes found advisable to concentrate the fertilizer applications for the rotation on this crop, and depend upon the residual effect on the following crops. Such a method of applying fertilizers seems logical where a complete mixture is used, but may yield disappointing results if the fertilizer ratios are not well balanced.

THE USE OF PHOSPHATE ROCK

Since phosphate rock is relatively insoluble in water it is essential that this material be applied at some time or in some way by which it will be brought into intimate contact with decaying organic matter. Used in connection with manure, phosphate rock has been shown to be almost as effective a carrier of phosphorus as acid phosphate. By scattering the rock over the manure before it is hauled to the field, distribution is effected without difficulty.

When applied alone, broadcast, it is believed that best results can be obtained by scattering it over the clover sod and plowing it under with the second growth of clover, or by applying it on top of some green manuring crop and plowing it under with this fresh material. Of the green manures the legumes are probably best for this purpose

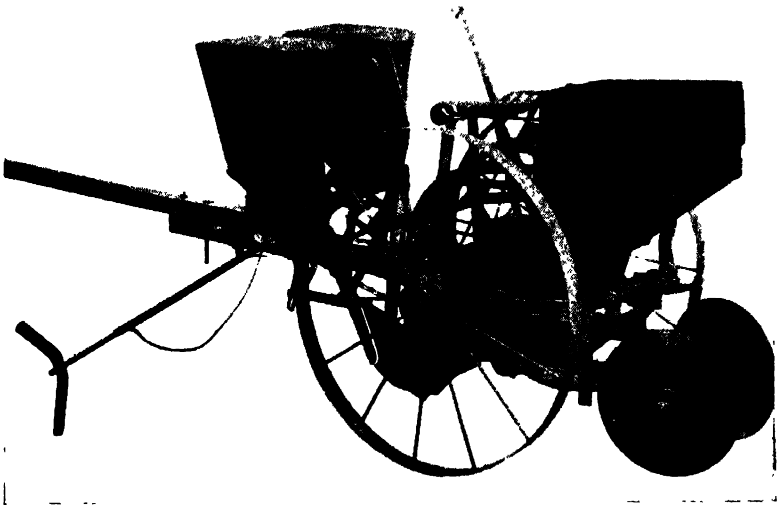

FIG. 33.—"If the fertilizer is separated from the seed, tuber or the root of the young plant by a thin layer of soil, injury can be avoided." (Courtesy of Soil Improvement Committee of the National Fertilizer Association.)

because of their high content of nitrogen and sulphur which are oxidized to their respective acids in the process of decay.

It seems best not to apply phosphate rock at the same time in the rotation as limestone, for reasons previously indicated. Probably in the ordinary three-year rotation, for example, the limestone could be applied on the clover sod the first rotation and the phosphate rock at the same point in the rotation the next time around.

THE DISTRIBUTION OF FERTILIZERS

With the use of larger amounts of fertilizer the question arises as to how this may best be distributed in the soil. It has ordinarily been assumed that, as the rate of application increases, the broadcast method of distribution is to be preferred as a means of preventing injury from too high a concentration of salts in the vicinity of the seed or the roots of the young plants. A further objection to row applications is found under conditions in which the soil is in a low state of productivity, since the residual effect of the fertilizer on the following crop is very apparent along the rows in which it was applied. Recently this problem has been receiving more consideration. An excellent review of the literature on the subject is given by Haskell.

DISTRIBUTION OF PHOSPHATIC FERTILIZERS

Where the fertilizer is chiefly or entirely phosphatic the danger of injury from too high concentration of salts is much less than with the more soluble nitrogen and potassium salts. In so far as the evidence on the use of phosphates is concerned, it seems doubtful whether injury is likely to result from row applications when used at the rate in which phosphates are ordinarily applied. Contrary to the usual belief, investigational work does not indicate that row applications tend to limit the distribution of the root systems of crops. If the crop " fires," as is sometimes the case with the row method of distribution, this is probably due to the rapid rate of growth of the crop with a corresponding increase in the rate of transpiration as a result of which available water becomes the limiting factor.

DISTRIBUTION OF COMPLETE FERTILIZERS

When phosphates are supplemented with carriers of nitrogen and potassium, such as nitrate of soda, or sulphate of ammonia, and muriate of potash, injury from too high

concentration of salts is likely to occur, particularly where fertilizers are applied at the rate of a ton or more per acre. Investigation of this problem indicates that if the fertilizer is separated from the seed, tuber or the root of the young plant by a thin layer of soil the injury can be avoided. In this connection there is opportunity for choice between having the fertilizer in front or behind, above or below, or at the side of the seed or tuber. Side applications seem preferable since the action of gravitational and capillary water tends to distribute the soluble salts vertically, and, if the fertilizer is dropped just previous to the dropping of the seed, there is always a certain amount carried forward to the seed by the machinery.

RAINFALL AS RELATED TO FERTILIZER USE

The danger of injury, either as a result of overstimulation of the crop or from too high concentration of salts, is likely to be much less in the humid regions having a high rainfall evaporation-ratio than in the drier regions where this ratio is low. It appears likely that the use of larger amounts of fertilizer with a somewhat more localized method of distribution will be somewhat more desirable in the humid East and South than on the drier soils of the West. In the Corn Belt the danger from drouth is always imminent. A little slower growth during the summer, with a delayed earing until after the drier weather of July and August is passed and with a hastening of maturity after the drouth is broken in early September, is most desirable. The "firing" of the crop indicates that the fertilizer is doing what it was intended to do, viz.: increasing the rate of growth of the crop. This indicates that the soil and the climate were not suited to such rapid growth and that the method of distribution was not correct or the rate of application was too heavy for the conditions to be met.

ECONOMY OF LABOR IN FERTILIZER DISTRIBUTION

In general livestock farming, phosphated manure can be applied to the clover sod and plowed under for the corn crop. If the acid phosphate was not added to the manure it would appear logical to apply it in small amounts in the corn row at the time of planting. Larger applications of phosphatic or mixed fertilizers could be made on the wheat at the time of seeding with subsequent top dressing in the spring with nitrate of soda or sulphate of ammonia sown by hand or with a grass seeder. Any residual effect would be of value to the clover crop and later directly and indirectly to the corn or other crops in the rotation.

With specialized crops, it is essential that the fertilizer be fitted to the crop and the climatic conditions so that the time, method and rate of application must be varied with the crop and weather. The cost of fertilizers, including the cost of distribution, being only a relatively small part of the cost of growing and marketing the crop, and the importance of earliness or quality, make it desirable to use fertilizers liberally and frequently in order to keep the crop under control in so far as this is possible. Where water is supplied by overhead or sub-irrigation it is possible to prevent injury from excessive use of fertilizers by heavy watering. Careful watching of the crop and the season permits the specialized crop farmer to anticipate the needs of the crop and to supply these as they arise throughout the season.

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